

NATURAL SPACE CONDITIONING FOR A TALL RESIDENTIAL STRUCTURE

by

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B.S. Architectural Studies University of Illinois, Urbana
June 1978

Submitted in Partial Fulfillment
of the requirements for the
Degree of

Master of Architecture

at the

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June 1980

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Natural Space Conditioning for a Tall Residential Structure

by Jamie Devol

Submitted to the Department of Architecture on May 8, 1980 in partial fulfillment of the requirements for the degree of Master of Architecture.

Abstract

A tall residential structure can be designed for high degrees of thermal and visual comfort and energy conservation through natural space conditioning. This thesis shows how passive solar heating, natural daylighting, and natural ventilation systems can be integrated as parts of the structure through the use of new and old building technologies.

This tall residential structure is in contrast to the typical single family housing of the mid-twentieth century. It is also in contrast to the mechanically space-conditioned towers built during an era of energy abundance.

The presented tower is an architectural response to local Boston climate. Its building form and flow-through organization are well-suited for natural space conditioning. New building technologies as well as age old passive techniques optimize solar insolation for heat and daylight as well as pressure and thermal forces for interior air flow.

The three major components of the finely integrated natural space conditioning system are individually addressed.

Passive solar heating for the south-facing building zones involves solar collection through direct gain windows, thermal storage in the structural building elements, and heat distribution aided by building organization. New building technology permits significant solar heating from diffuse radiation for the north-facing units. An appropriate auxiliary heating system, sympathetic to the overall decentralized method of heating, is selected.

High quality daylighting is achieved through well recognized methods in combination with some relatively new technologies.

Natural ventilation, consistent with passive solar heating and natural daylighting, is developed for each unit through the use of prevailing summer winds. The tall structure invites the use of the stack effect for controlled air flow over pressure differentials between a low inlet and a high outlet.

As an inherent part of the structure, natural space conditioning criteria combine with housing requirements to generate the building form. The result is a tall residential structure in harmony with the environment.

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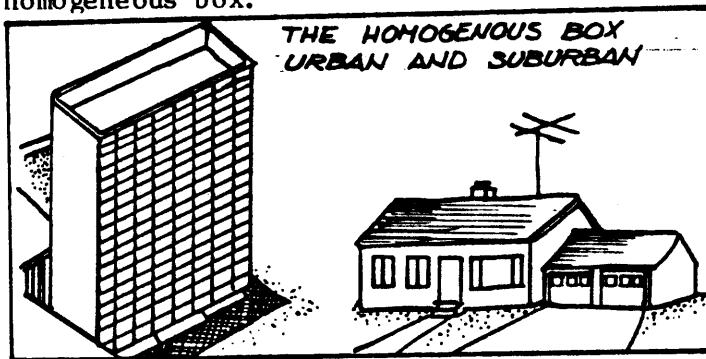
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INTRODUCTION

Introduction

Natural space conditioning for a tall residential structure is a retreat from the architecture of the affluent mid-twentieth century. During this era of unlimited energy supply, buildings were constructed independent of local climate. Mechanical space conditioning systems guaranteed environmental comfort in any shelter under any conditions. This fueled the proliferation of the homogeneous box.

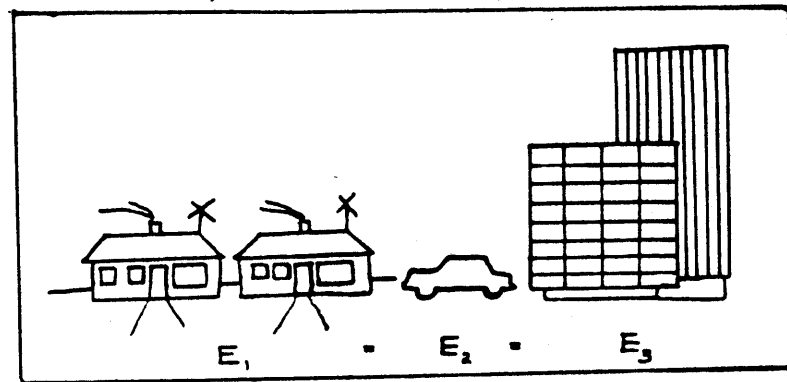


The homogeneous box comes in two forms, urban and suburban. Millions of acres of countryside have become flypaper for the suburban breed of box, the single family home. These vulnerable little boxes are sprinkled at regular intervals with no regard to the forces of nature. Mechanical equipment is required to continually pump energy into these boxes in a valiant effort to maintain

a comfortable, but bland interior environment.

Large urban boxes, a mere multiplying and stacking of horizontal boxes, are of no improvement; for they, too, fail to respond to the natural environment. They have degenerated into faceless envelopes accomodating multitudinous mechanical and electrical facilities, a frantic effort to regulate interior comfort.

The arrangement of small boxes in the suburbs and larger ones in the city requires great mobility due to separation of function, living to shopping and working. Isolation from nature and artificial uniformity of interior comfort is tenuously preserved between these two stations by a stream of oversized automobiles, environmentally controlled with heaters, air conditioners, and tape decks.



Such blatant disregard for the environment results in an incredible amount of wasted energy. About 1/3 of all energy used in the United States is consumed by buildings. (Caudill, A Bucket of Oil, p.8). At least half of this energy, 80 billion gallons of oil, is wasted through thoughtless building design.

Energy conservation, alone, is reason to design for natural space conditioning. Passive solar heating, natural daylighting, and natural ventilation utilize free energy with infinite renewability.

Energy conservation is also argument for tall building construction as opposed to the production of multitudes of single family houses. Energy is saved through shared resources such as land, utilities, structure, and materials. Medium to high density housing implies an urban setting, close to work and shopping. Walking, bicycling and mass transit replace the inefficient car, "the most visible symbol of conspicuous consumption." (Caudill, A Bucket of Oil, p. 15).

Natural space conditioning is cost effective. Passive solar heating, natural daylighting, and natural ventilation require no mechanical equip-

ment. The building, itself, in response to the cyclic forces of nature, maintains a comfortable interior environment. As such, the cost of natural space conditioning is absorbed in the traditional building costs of structure, glazing, and finish materials.

Even when furnished with mechanical back-up systems, initial cost may be no more than that for conventional structures. Total expenses over the life of the building are significantly less through energy conservation measures.

Isolation from the out-of-doors, a symptom of the spendthrift years of limitless energy, is depressing, if not demoralizing. Natural space conditioning provides a play between indoors and out, which improves the quality of life. Passive solar heating, natural daylighting, and natural ventilation heighten an individual's awareness of the recurring natural cycles by which the human is governed...from night to day and from season to season.

As an inherent part of the building, natural space conditioning systems are form-givers to architecture. Criteria for passive solar heating, natural daylighting, and natural ventilation

provide reason for design resolutions. This lends a definitive character to regional styles. The homogeneous box, on the other hand, is isolated from nature and dependent on mechanical environmental control. With no hints for design from the environment, the building often takes on an arbitrary form, independent of location or climate. This has no reason.

The premise of this thesis is that a tall residential structure can be designed for interior environmental comfort and energy conservation through natural space conditioning. Passive solar heating, natural daylighting, and natural ventilation systems are finely integrated as parts of the structure through the use of new and old building technologies.

Passive solar heating depends on direct solar gain for south-facing building zones. Thermal storage is inherent in the concrete structural system, common to many tall buildings. A flow-through organization allows the convection and uniform distribution of heat from the lower levels of solar collection and storage to the upper levels, isolated from direct gain.

A new technology permits passive solar heating for north-facing building zones. Heat mirror, used as a glazing material, is transparent to incoming short wave radiation from diffuse northern light. It is opaque to the returning longwave infrared rays. Heat energy from both the sky vault and internal gains are trapped within the space, thereby contributing almost half of the north-facing annual heating load.

Natural daylighting is optimized by old tried and true building methods such as high ceilings, tall windows, and shallow rooms with white walls. Building form allows for multi-directional lighting while light shelves, reflective louvers and vertical shading fins control light penetration and uniformity.

Natural ventilation depends on the flow through organization used in heat distribution. The crenelated building form creates pressure differentials inducing air flow from a field of positive pressure to one of relative negative pressure. The vertical shading fins create pockets of negative pressure in addition to their light control functions. Selected fins also accommodate ventilation stacks, one for each living unit. These stacks cause air flow via pressure differentials that exist between a low inlet and a high outlet.

Integration of these natural space conditioning systems with each other and with the building is obvious by examining building elements individually. For example, the "clerestory" windows, in combination with the light shelf at transom

height, collect and distribute solar heat gain, natural daylight, and overhead ventilation. The vertical shading fins control low sun angle heat gain and diffuse the accompanying light for pleasant natural lighting within the space. In addition, they create negative pressure fields for air flow outlets and accommodate flues for stack effect ventilation. The overall organization permits solar heating, natural daylighting and natural ventilation throughout the entire building.

A detailed description of this integrated design response to natural space conditioning criteria appears in Chapters 1, 2, 3, and 4.

Chapter 1 describes the tall residential building as it is organized by vertical neighborhoods.

Chapter 2 focuses on passive solar heating. Objectives, limitations to passive solar heating in tall structures, and the design response to passive solar heating objectives are discussed. Appendix A provides direct and indirect gain calculations, supporting materials for this design response.

Chapter 3 focuses on natural daylighting.

It, too, lists objectives, limitations to natural daylighting in tall structures, and the design response to these objectives. Appendices B, C, and D provide supporting material for the design response through light studies and recommended daylight factors.

Chapter 4 focuses on natural ventilation. Objectives, limitations to natural ventilation in tall structures, and the design response to these objectives are discussed. Appendix E presents the wind tunnel studies and Appendix F provides stack effect calculations.

An auxiliary heating system is chosen in the final chapter. Appendix G evaluates the initial cost of the chosen decentralized scheme to that of a conventional heating system.

CHAPTER 1

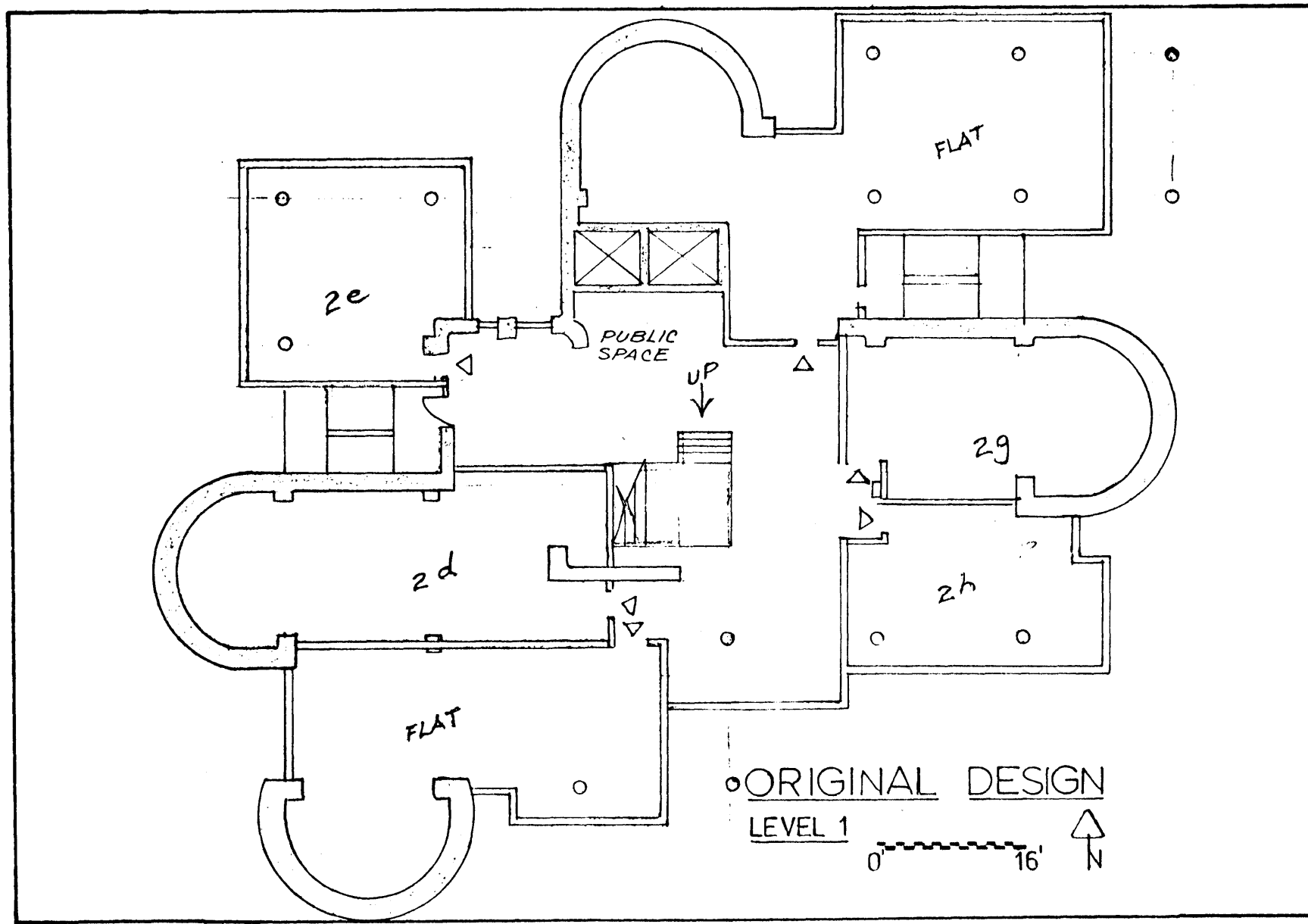
THE TALL RESIDENTIAL STRUCTURE

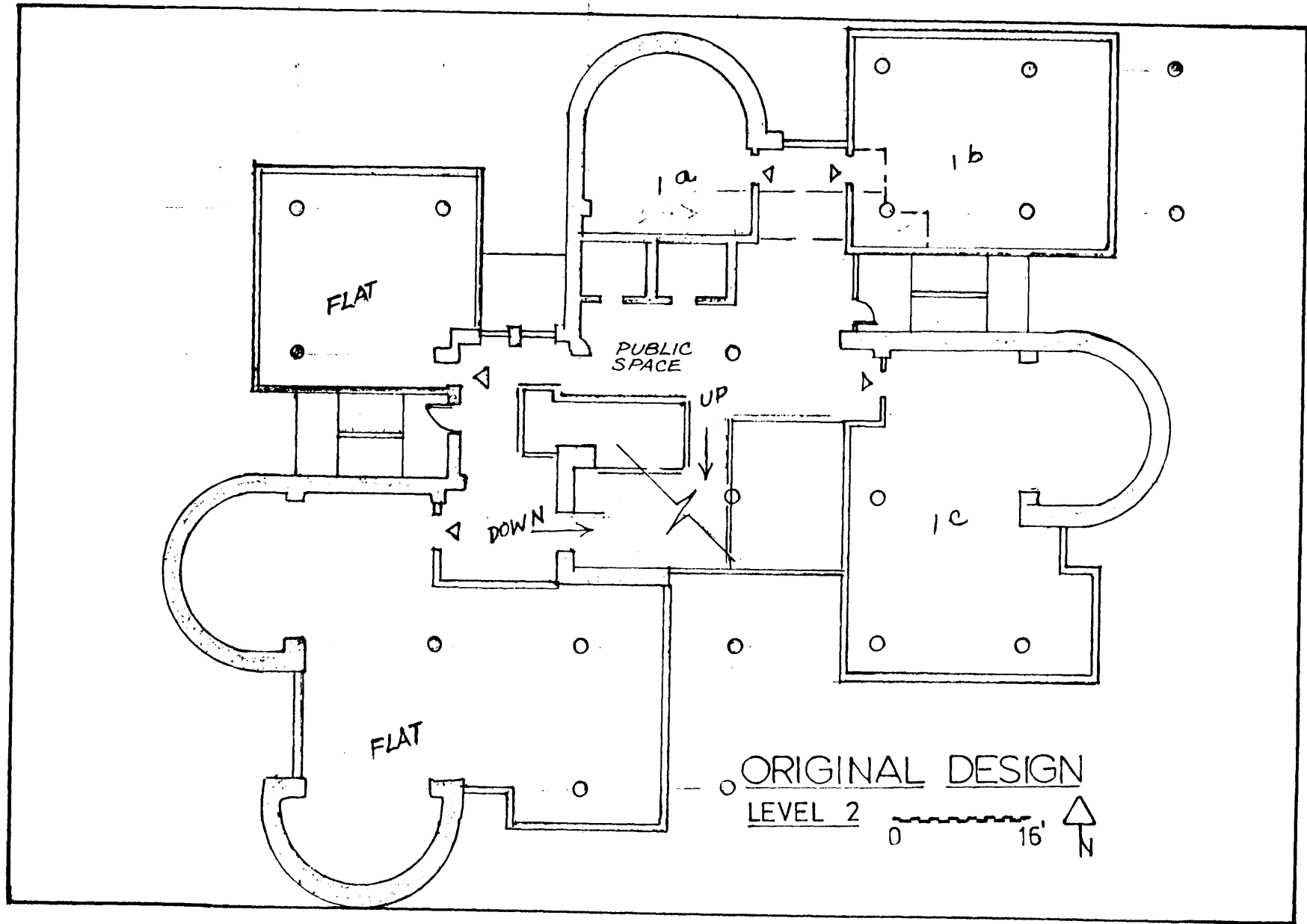
Chapter 1

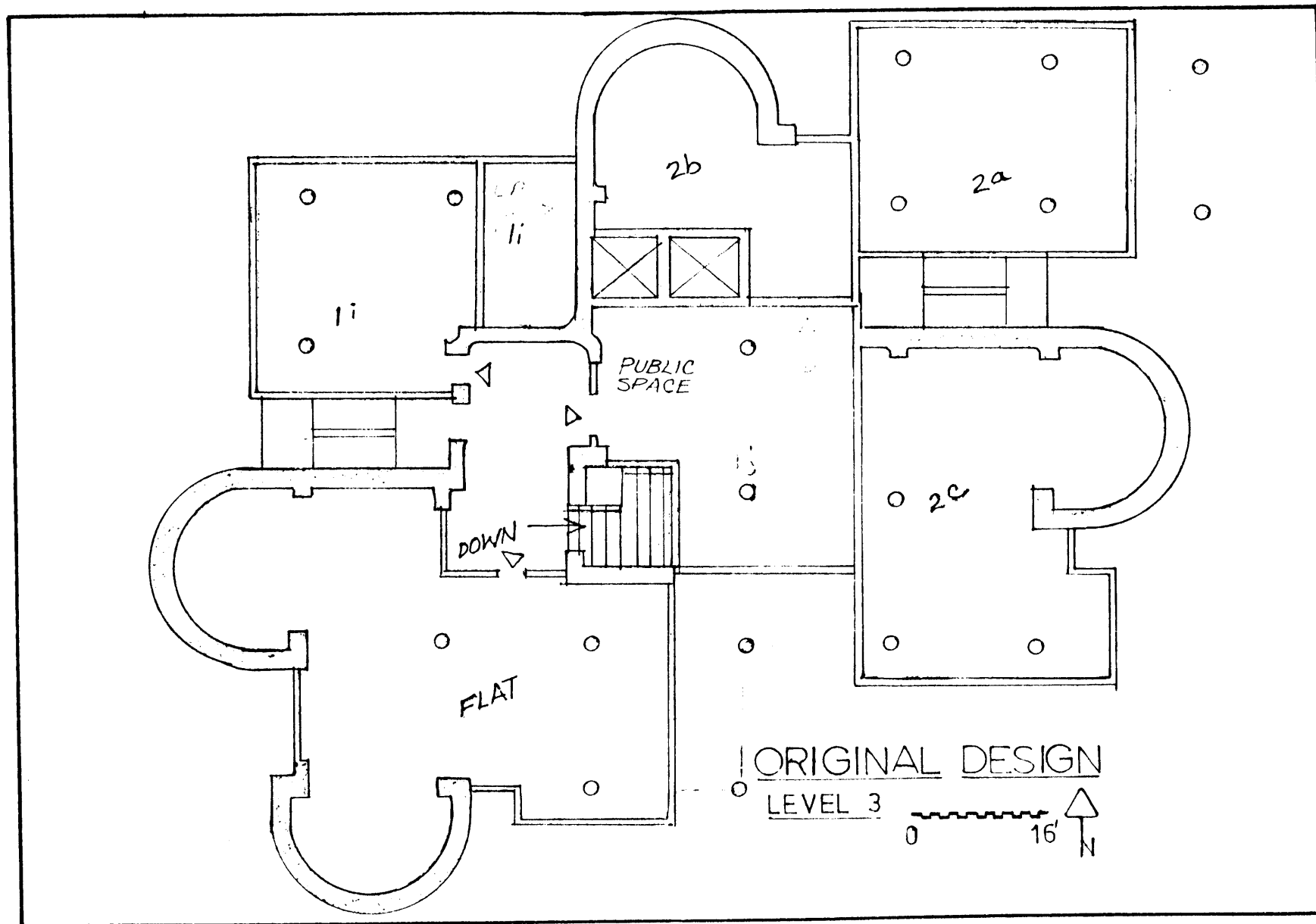
A design developed in Professor R. Slattery's tall building studio serves as a base from which to generate a tall residential structure using natural space conditioning criteria. The studio project, a "small tower," is organized around a series of vertical neighborhoods. Fifteen dwelling units within and around a four story community common define one vertical neighborhood. Five neighborhoods compose the tower.

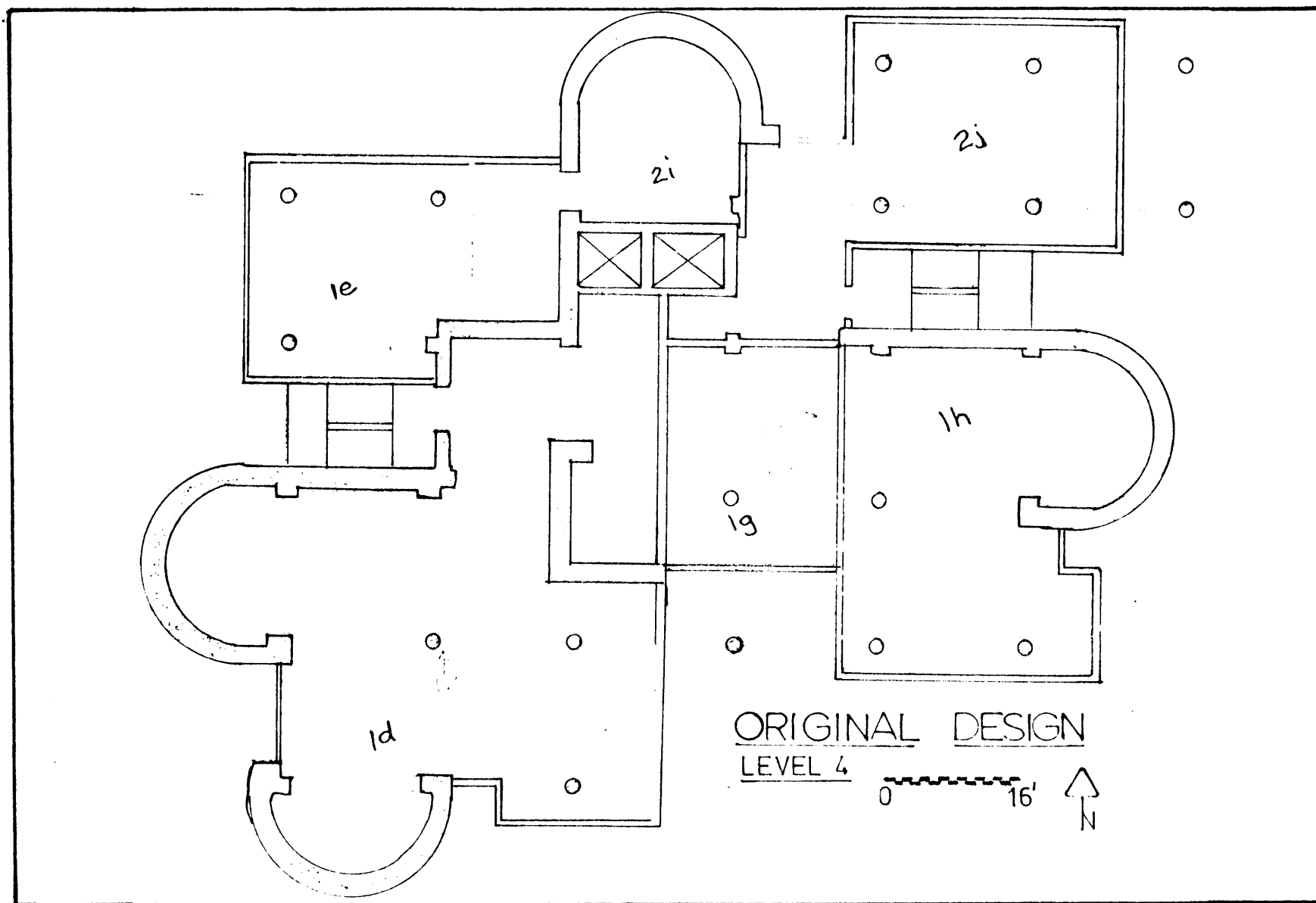
The design criteria, to create a three-dimensional composition of dwelling units and common space, interconnected by a continuous circulation spiral, generated the design. The crenelated building form lends itself well to the application of natural space conditioning criteria. Many of the living units, as well as the public space, benefit from flow-through organization, with multi-levels and three or more exposed weather walls.

Through consideration for passive solar heating, natural daylighting and natural ventilation, a new structure evolves. Comparison of the original design to that at the end of this chapter shows the changes.









Natural space conditioning criteria is applied to the common space and to each unit individually. This allows for flexibility of the interior environment according to user needs.

Natural space conditioning criteria:

- 1) Elongates the building along the east-west axis;
- 2) Increases the amount of south-facing double glazing and the amount of north-facing heat mirror;
- 3) Decreases the amount of east-west glazing;
- 4) Alters wall elevations sections, and materials;
- 5) Changes the neighborhood and unit layout for better flow-through organization;
- 6) Alters room proportions, decreasing room depths while increasing ceiling height;
- 7) Changes partition placement and design;
- 8) Suggests room finish.

In spite of these and other changes, the basic ideas of the original building remain intact.

The 240' structure is subdivided into five, four-story neighborhoods. Each neighborhood is composed of a three-level communal space. Fifteen dwelling units are oriented in and around the community common.

The main elevator stop for each neighborhood occurs at the second level. Concrete steps lead to the first and third levels of the public space. All unit entries are off this community common.

The character of this public space is one of a neighborhood on a hill. Natural daylighting and ventilation render the space as exterior. The quality of interior light fluctuates with the exterior daylight, while cooling breezes heighten the sense of the outdoors. By opening sliding glass doors along the south-facing expanse, and a limited number to the north, the neighborhood becomes a sheltered exterior space high above the ground. The south-facing sliders open onto an outdoor balcony, an exterior extension of the neighborhood.

A profusion of plants not only visually suggests an outdoor space, but lends dampness and the smell of soil to this sunlit common. Typical of outdoor neighborhoods, concrete paths for circulation and play are defined by these garden areas. Park benches and porch swings interspersed with plants offer "outdoor" seating in sunshine or shade, in direct breeze or built shelter.

A convincing symbol of a true neighborhood

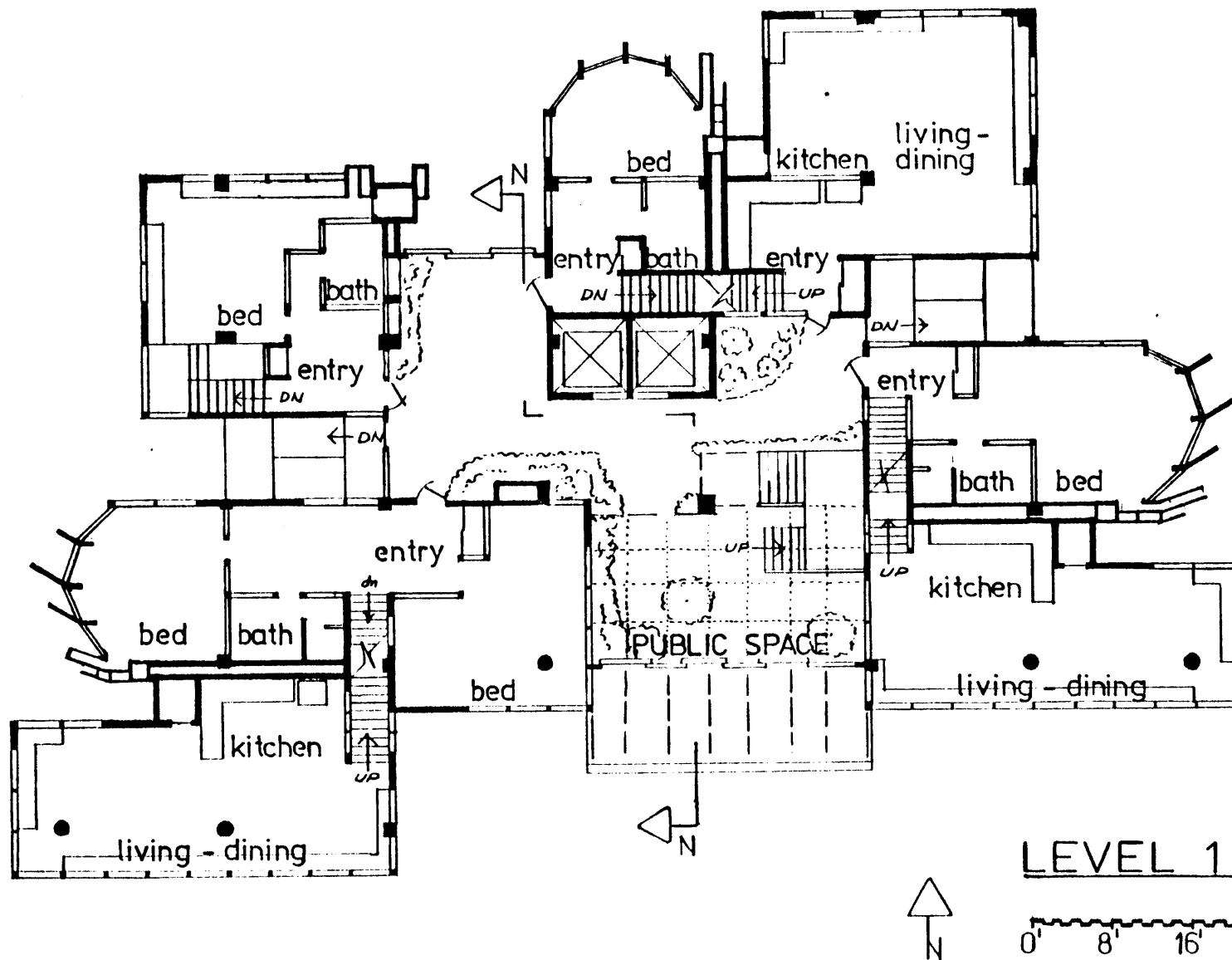
is a laundry-filled clothes line. The laundry facilities on the second level to the north, include an indoor-outdoor drying porch, perceptually reinforcing the neighborhood character.

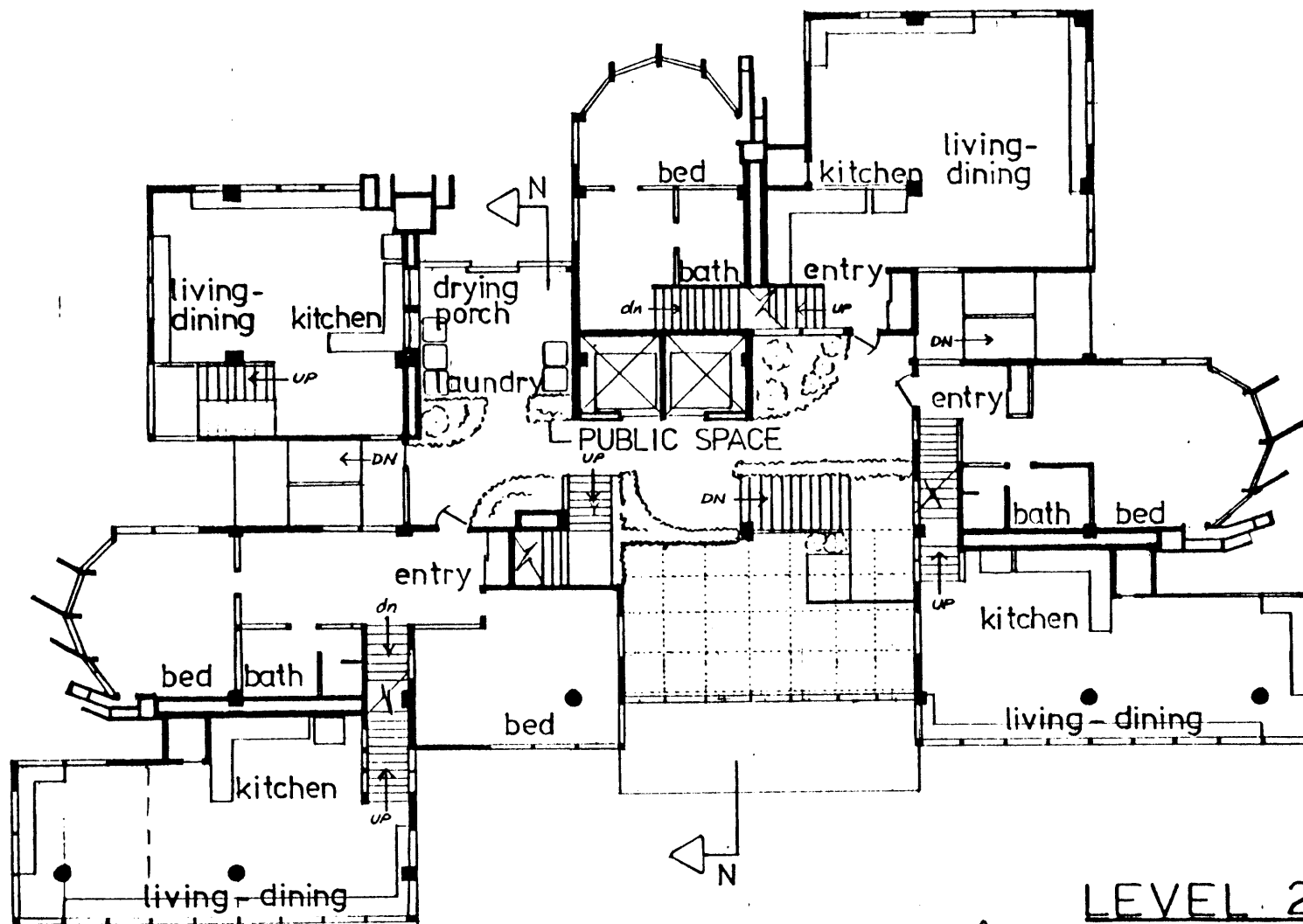
The architectural detailing of the unit facades and entries is exterior in character, with weather walls, operable windows, transoms, and planters.

The typical unit, itself, reinforces the outdoor quality of the neighborhood common. The transom over the door admits light from the vertical neighborhood, suggestive of a door to the exterior. Immediately inside the entry is a space for bicycles, muddy boots, and wet umbrellas, as well as the typical entry closet for overcoats.

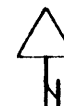
This second-level entry permits one to retreat unseen to the bedroom or bath, or to descend the stair shaft to the kitchen-dining-living areas. This organization divides the living unit into two zones, an active zone and a quiet zone. These are separated by a core wall and a level change of one story. Both portions are backed against the core wall...the bath and bedroom upstairs, above the kitchen-dining-living area.

The design for a tall residential structure with natural space conditioning is presented on the following pages.

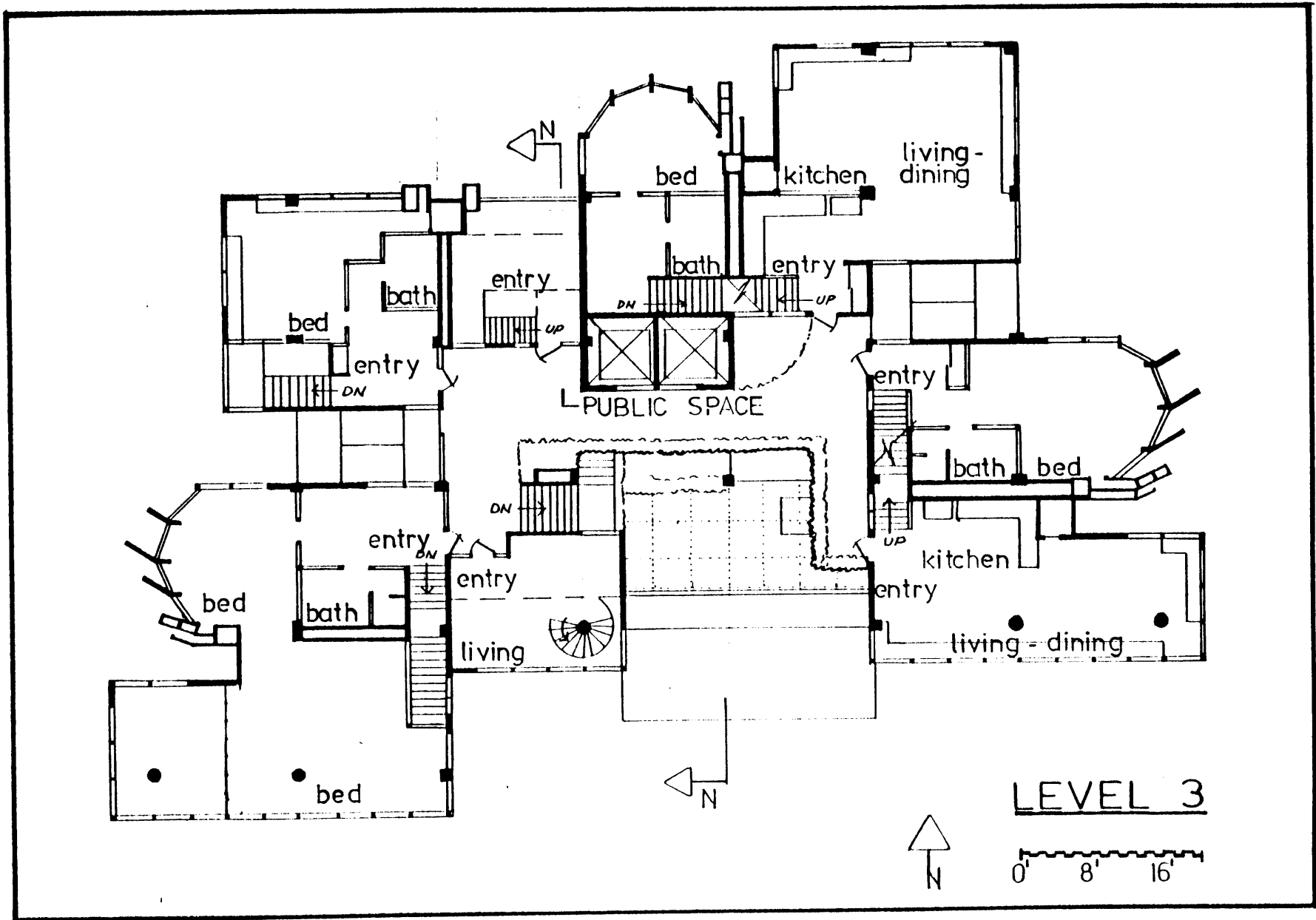


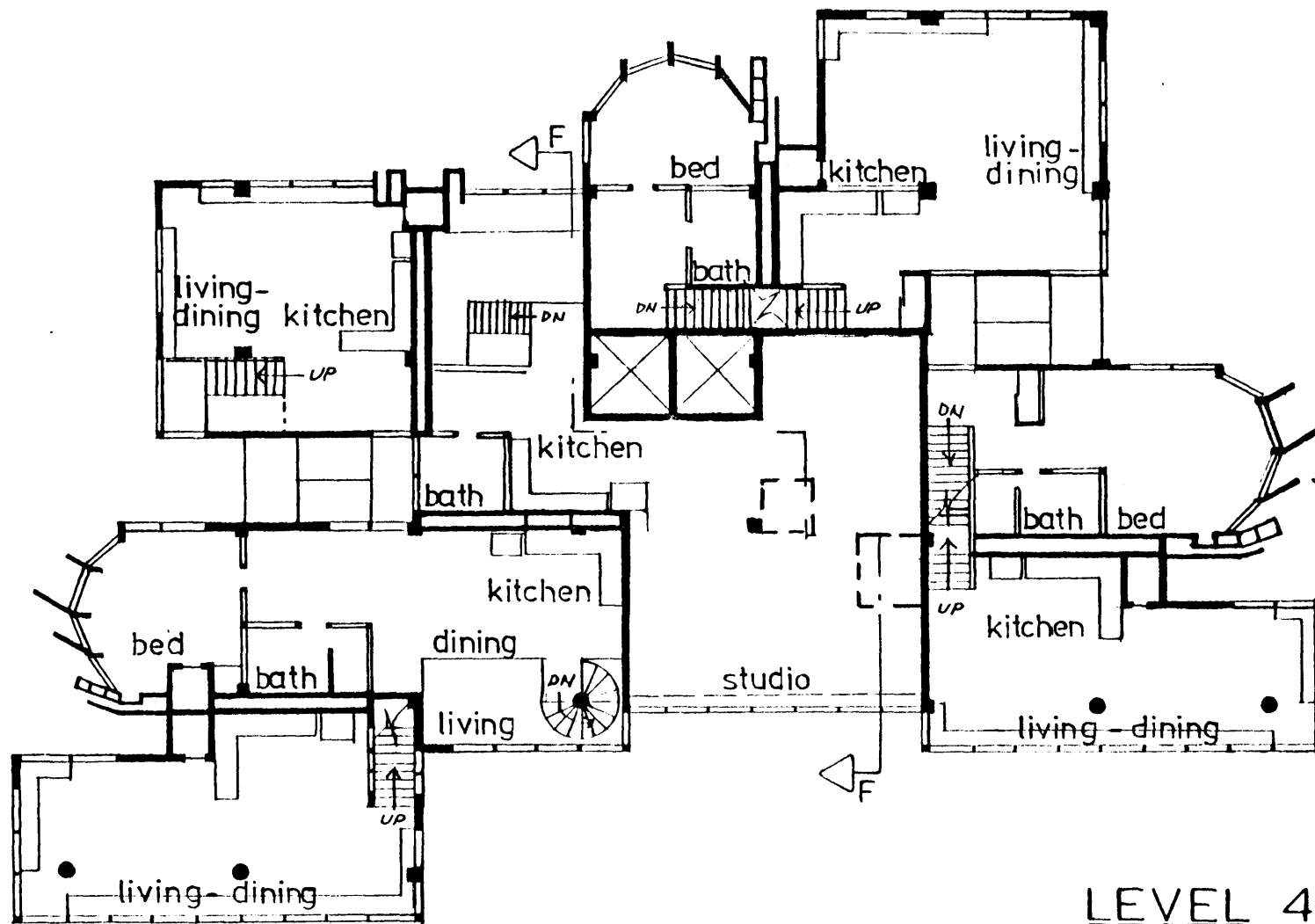


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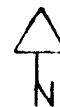


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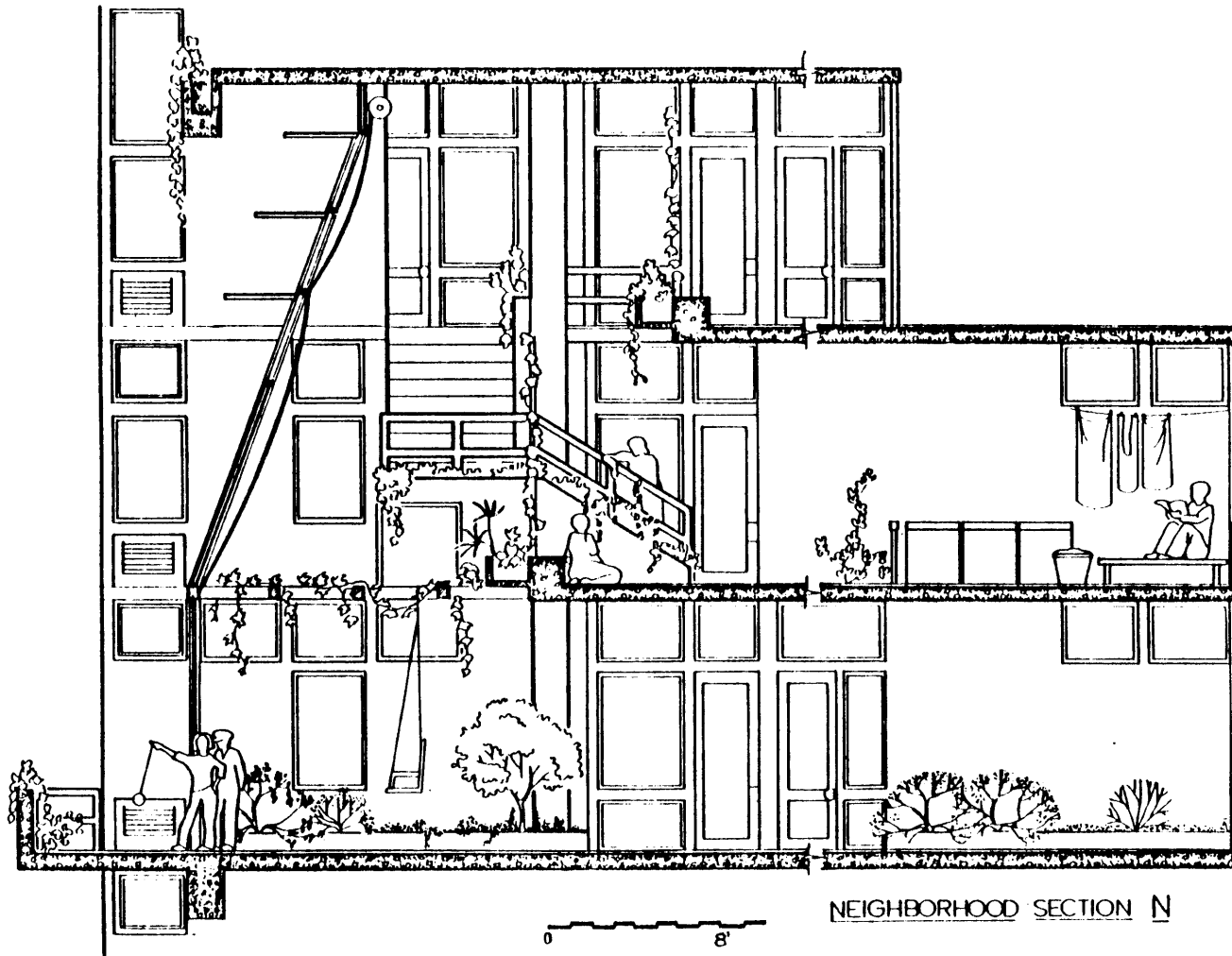


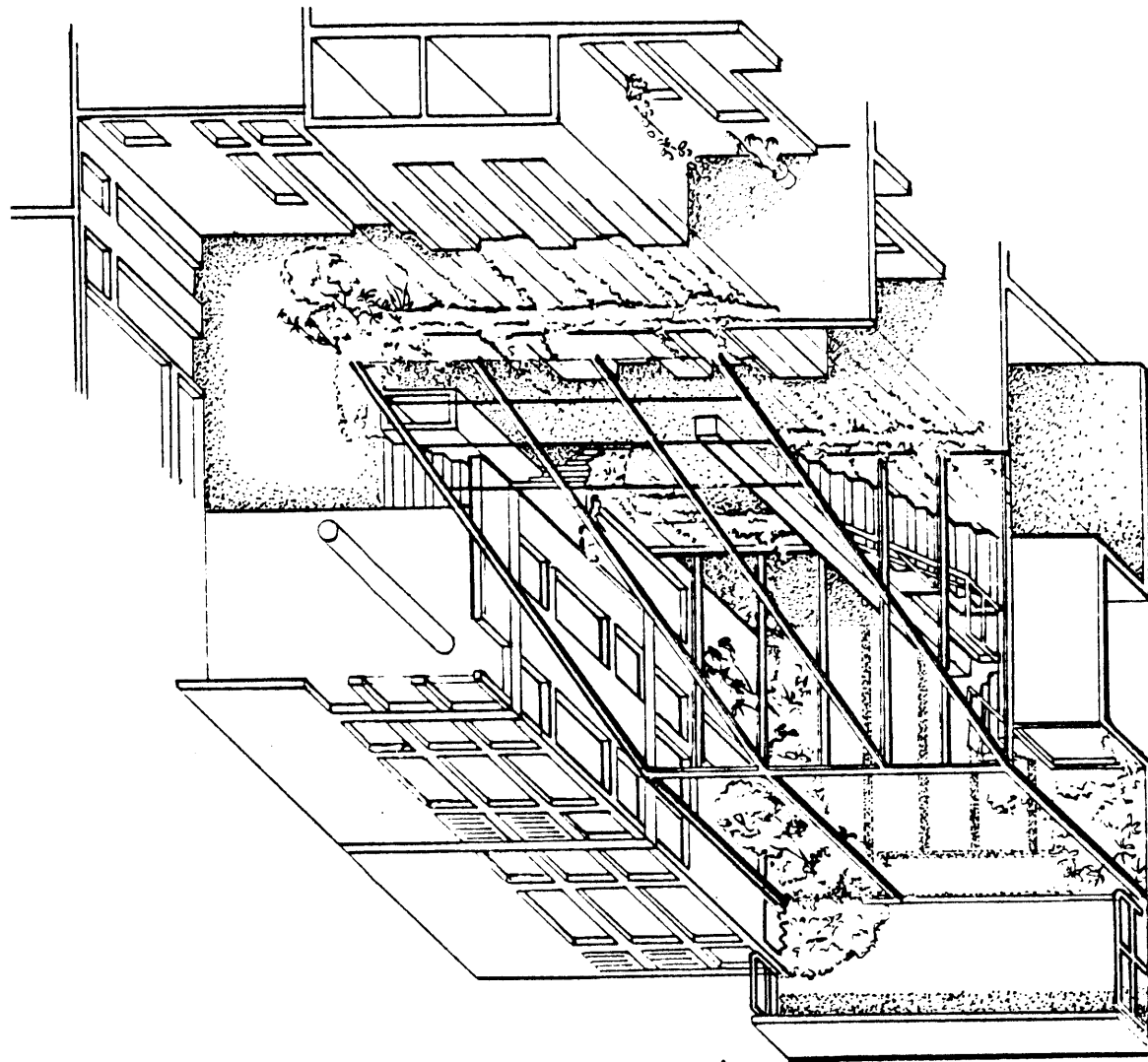


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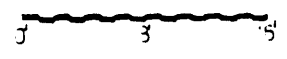


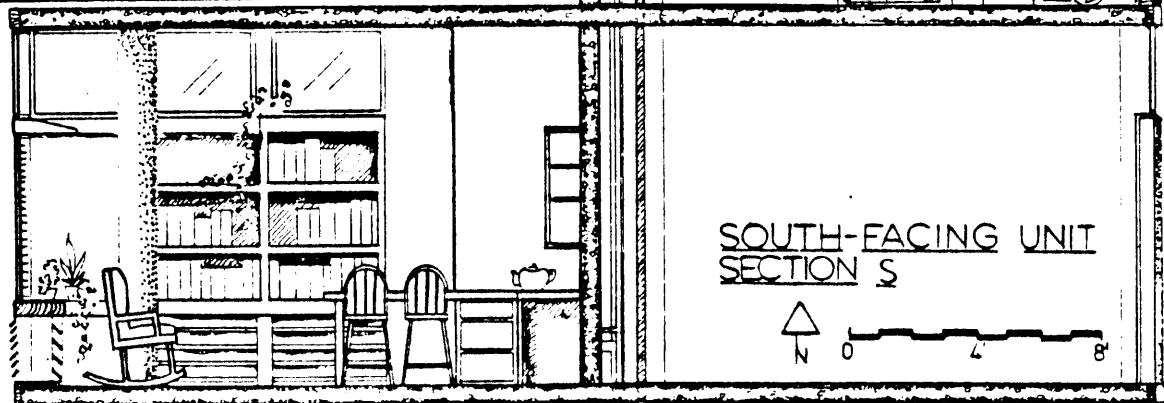
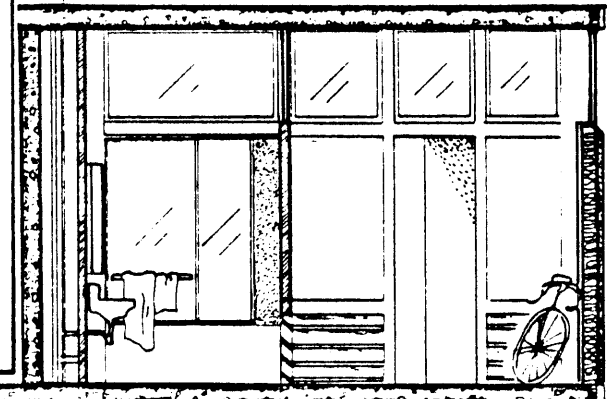
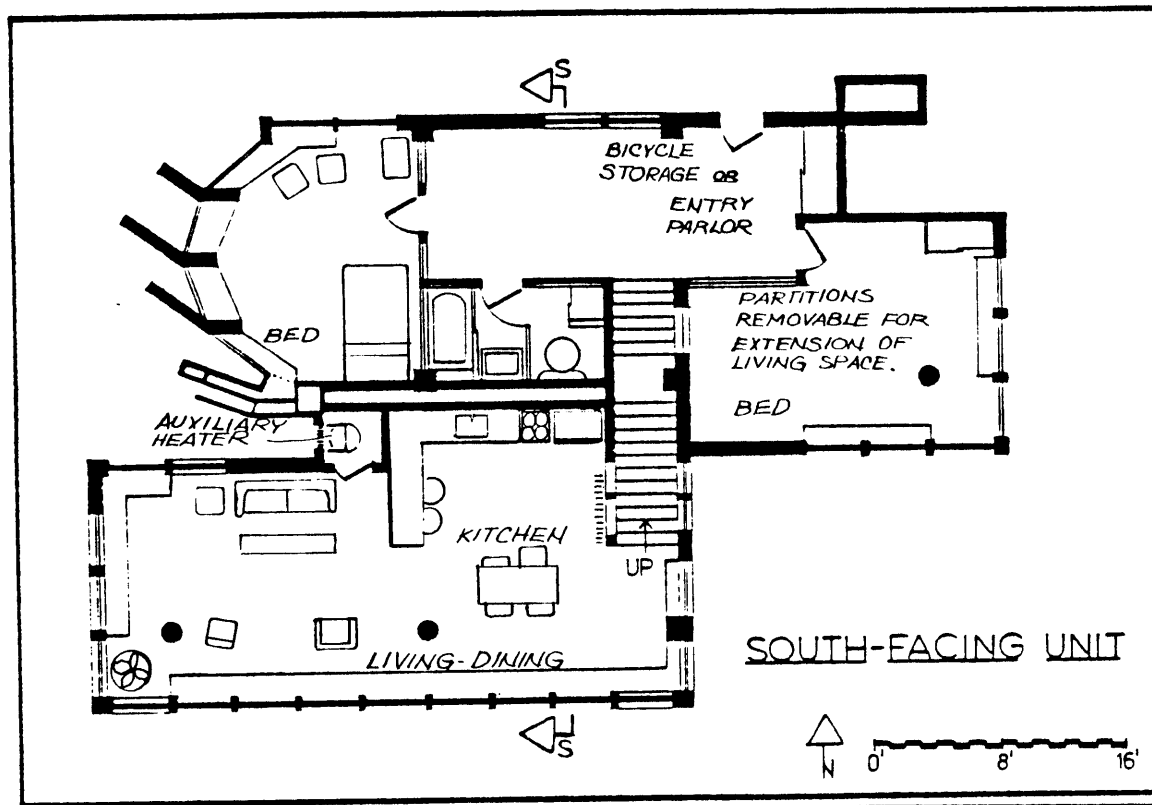
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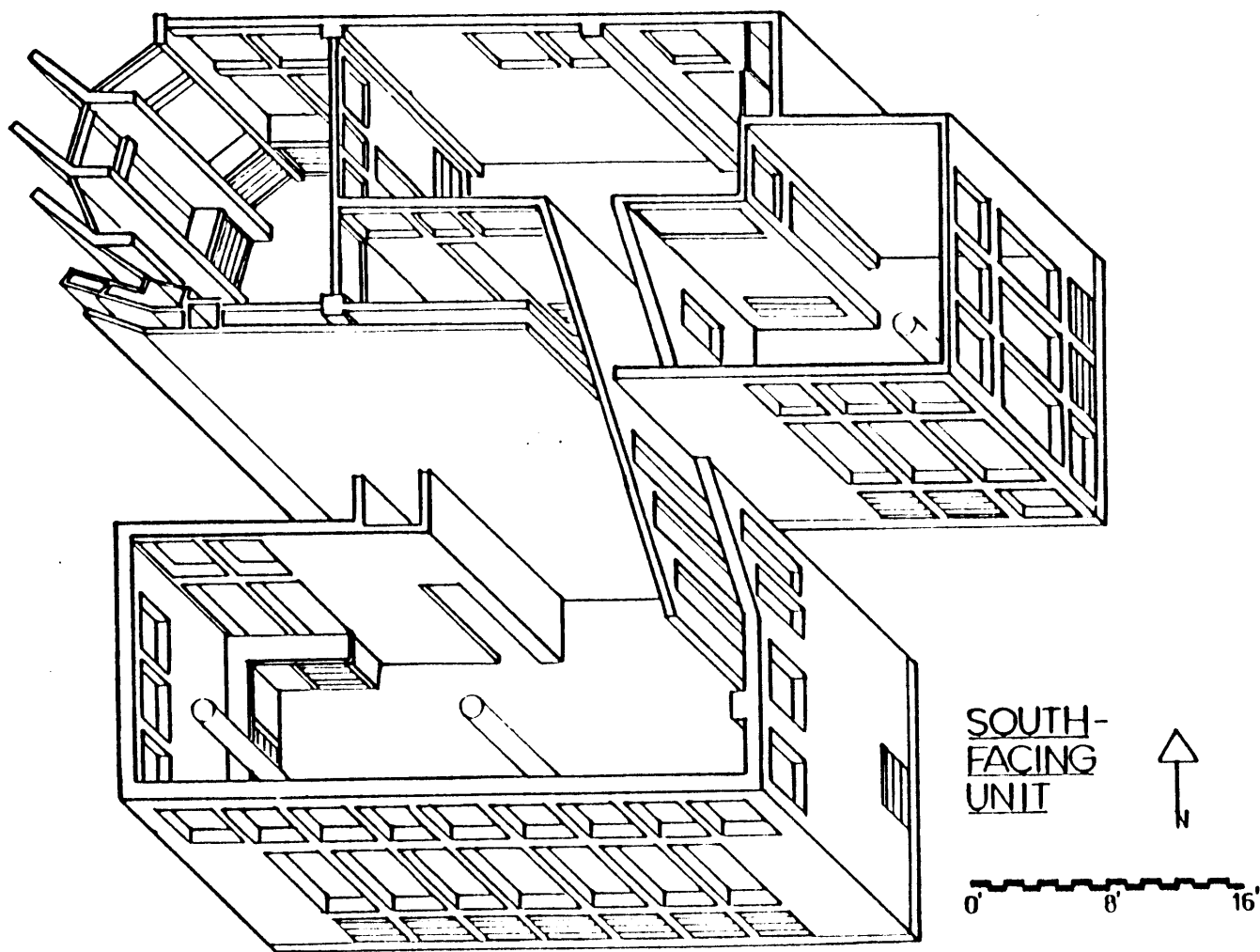


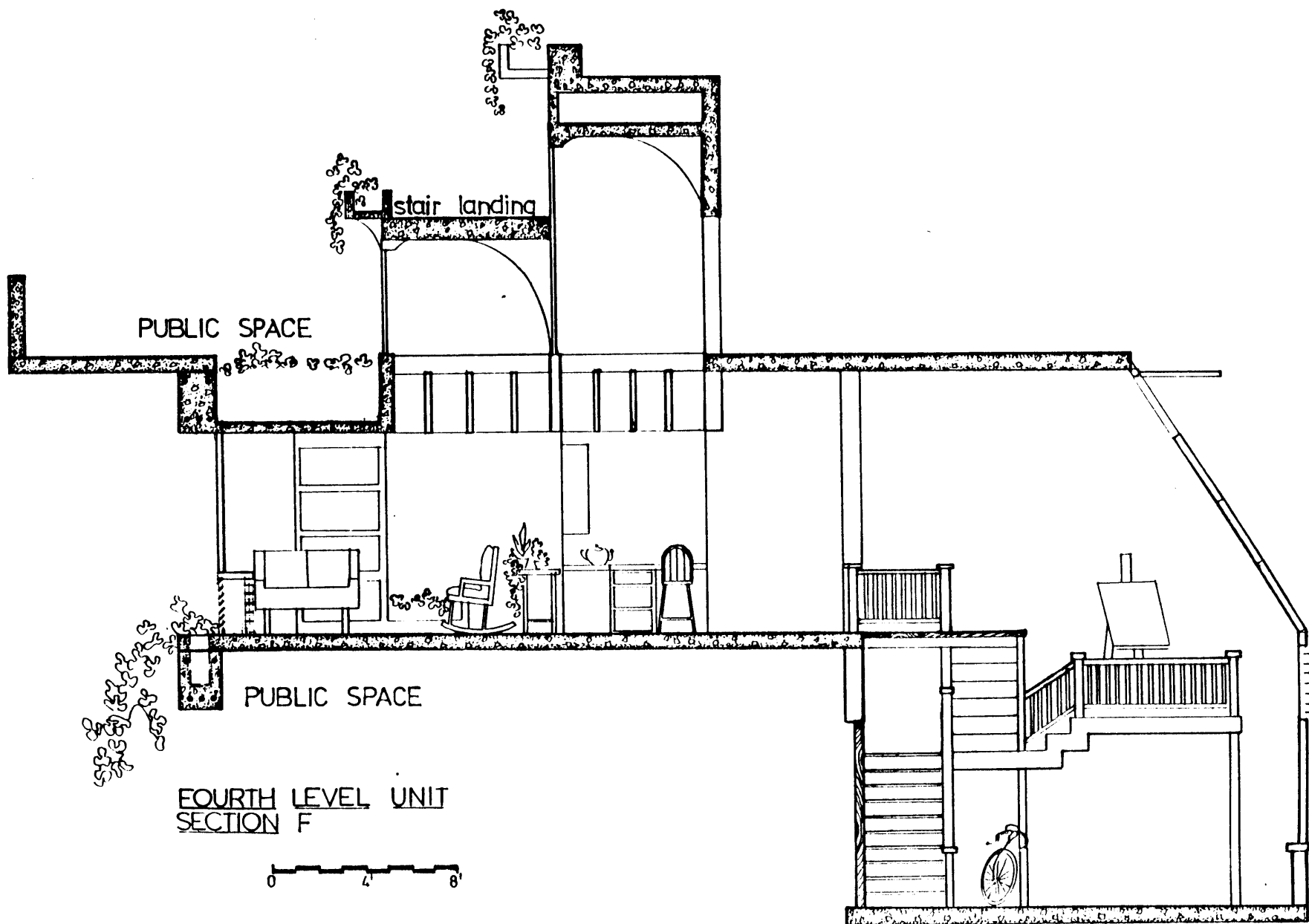


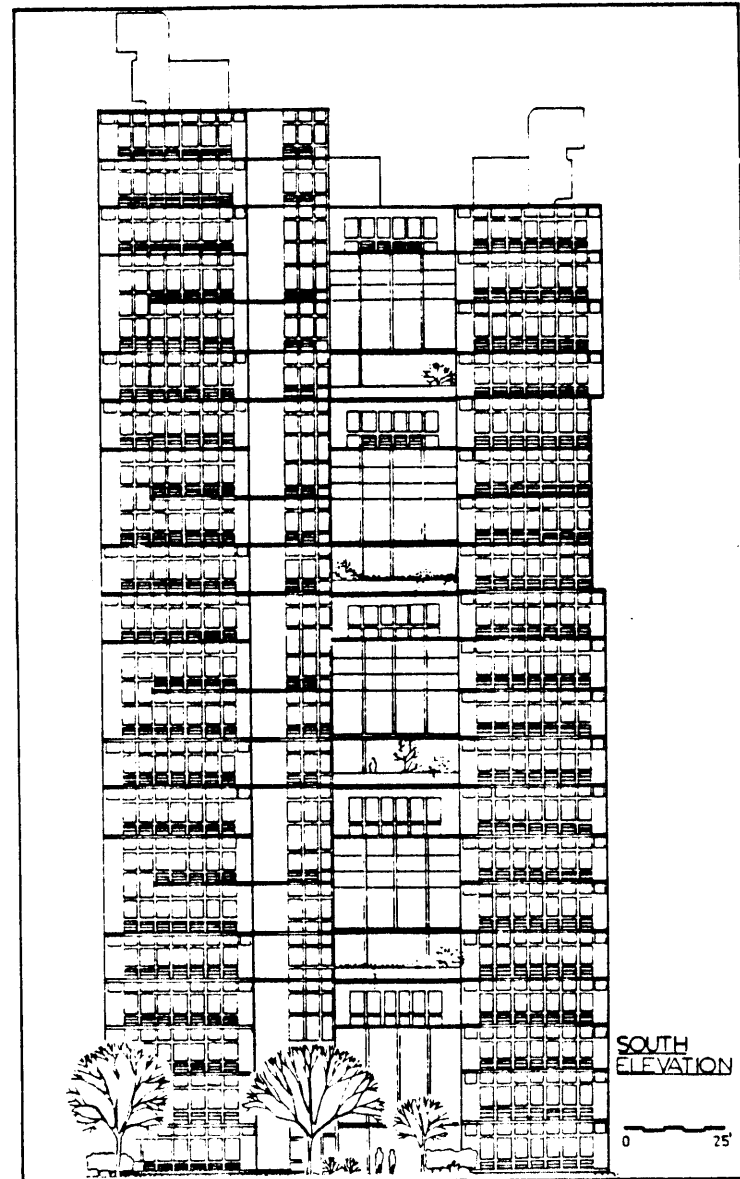
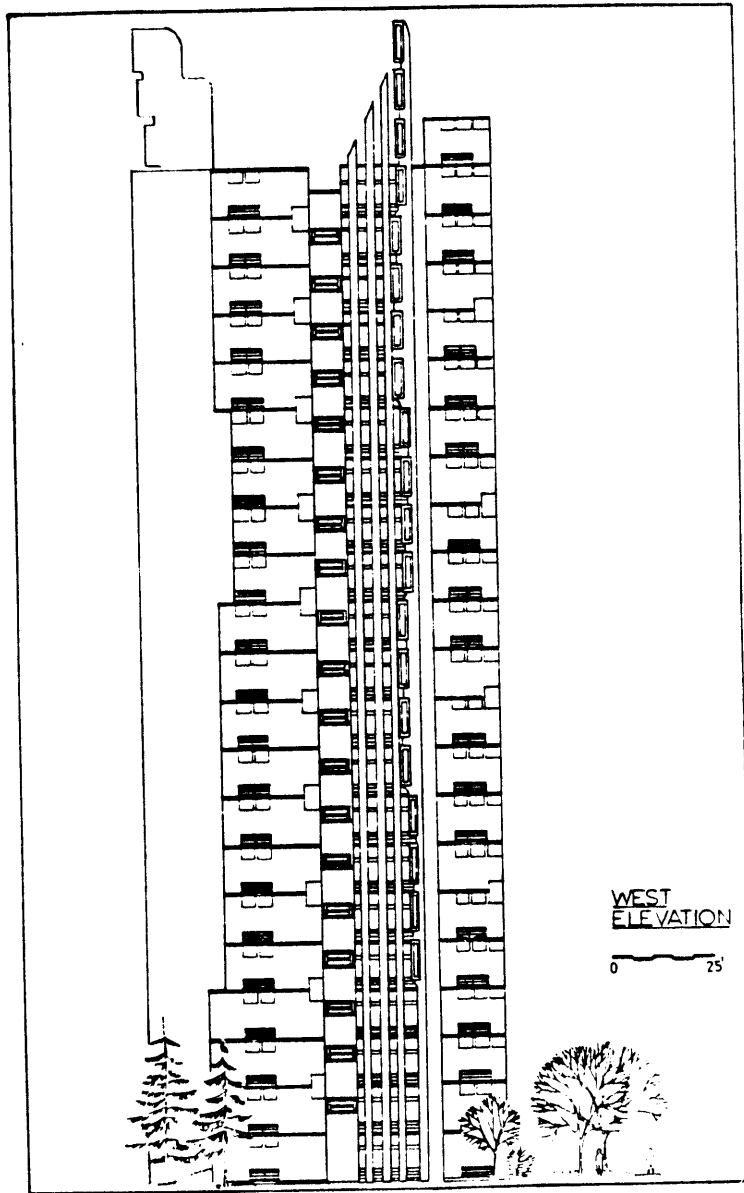
VERTICAL NEIGHBORHOOD

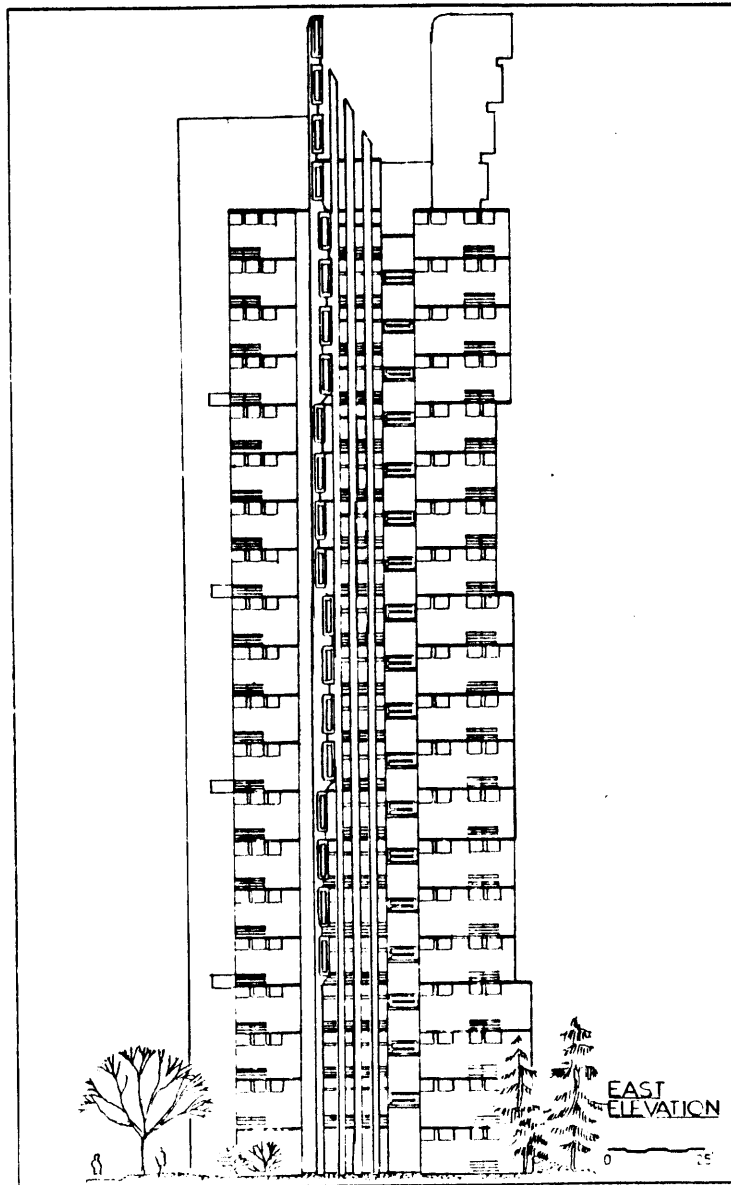
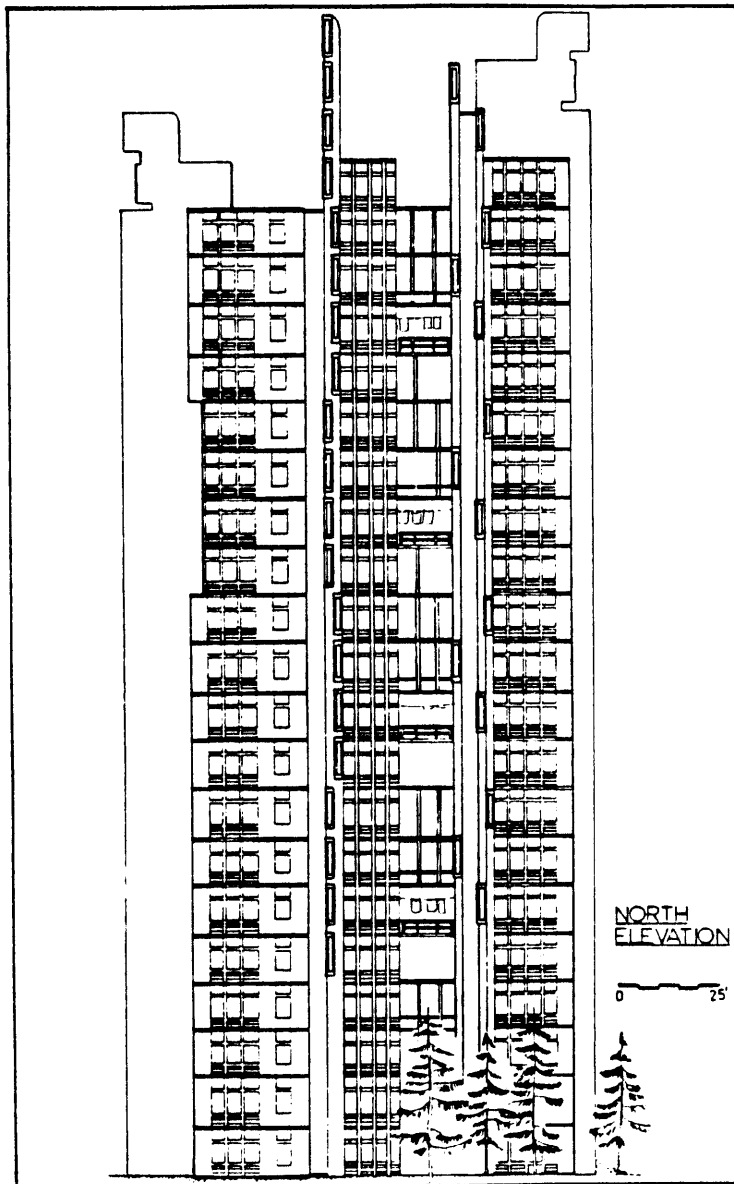












CHAPTER 2

PASSIVE SOLAR HEATING

Why Passive Solar Heating?

Widespread solar heating could reduce national fuel consumption and environmental degradation by 10% or more. (Anderson, The Solar Home Book, p.1). No matter what mechanical space conditioning systems are to be installed, all buildings should be optimized for natural thermal comfort and energy conservation.

Solar energy is conveniently distributed throughout the world. It is independent of expensive transportation networks and ugly political policies. Its use lessens dependence on government and industries which monopolize concentrated energy supplies for economic and political power.

A passive solar heating system is the building itself; building materials couple as the heating mechanism. Such simple approaches to environmental control are often less expensive and more reliable than conventional mechanical systems or high technology methods of solar heating.

Passive solar heating must be an important consideration in each design step. This results in design decisions backed by reason, a shelter that reflects "an understanding of the sun's power, generosity, and cruelty." (Anderson, The Solar

Home Book, p. 1).

Climates across the globe differ, and solar-tempered structures vary in response to the local climate. Therefore, passive solar design is a potential cause for a rich diversity of regional styles.

Arguments in favor of passive solar heating abound, and all can be applied to this particular design. Solar design is most prevalent in single-family housing, but as formerly mentioned, should be a consideration in any project.

The vertical neighborhood is of an outdoor character, a quality reinforced by passive solar heating. Sunshine is almost the definition of outdoors, and plenty of sunshine must be admitted into a passive solar structure. Even in tall structures, inhabitants need not be isolated from the world outside. Windows designed for solar gain also provide views. The effective use of the sun requires occasional tasks such as adjusting louvers or moving insulation. This attunes people to their own environment and building. It makes them more aware of the wasteful habits of a consumption society.

Passive Solar Heating Objectives for Direct Gain

1) As a solar collector, the building's form, orientation, and organization should welcome solar gain when needed, reject it when not, in order to maintain a comfortable interior temperature.

South-facing windows are effective solar collectors, accepting the winter sun, low on the horizon, while rejecting the hot overhead summer sun with simple sun control devices. Distributing excess heat throughout the building mass conserves that energy for nighttime and overcast days, lowering the use of auxiliary heating.

2) As a heat storehouse, the building should offer sufficient amounts of thermal storage mass in order to limit the temperature swing.

The greatest heating load occurs at night whereas almost all of the solar gain takes place between 8 in the morning and 4 in the afternoon. If the storage material is unable to absorb that portion of incoming radiation which exceeds the immediate heating load, overheating occurs. And with lack of storage material or with excessive heat loss, nighttime and cloudy day temperatures will dip to uncomfortable levels. If ordinary building materials double as the thermal storage

mass, the sunlight must be diffused at the window and distributed over a large surface area of the storage material. This is due to the relatively low effective heat capacity of many building materials. The amount of mass required may be 5 to 6 times the area of south-facing window.

If beam solar penetrates the glazing to a targeted mass, phase change materials must be used to prevent overheating. These materials are capable of absorbing the intense energy contained in direct sunlight while decreasing the surface area necessary for storage. Buildings with large areas of south-facing glass inundated with direct sunlight are susceptible not only to overheating but to glare as well. Control of this sunlight for visual comfort is a necessity in a good passive heating design. This is dealt with in the proceeding chapter.

3) As a heat trap, the building must conserve thermal energy in order to substantially reduce auxiliary heating loads.

This implies more than capturing and storing solar radiation. Lowering building heat loss is

an implicit part through the use of ample insulation, tight construction, double glazing, and heat mirror. Heat mirror accepts short wave radiation while reflecting back into the room the longwave thermal radiation. It traps energy from diffuse northern light and that from internal heat gains, significantly lowering auxiliary heating requirements in north-facing building zones.

Limitations to Passive Solar Heating in Tall Structures

Many conventional tall buildings are undifferentiated geometric forms. They are composed of a repetitive rhythm of rooms wrapped around a core or mundanely placed, side by side, along either edge of a corridor.

The local exterior environment has no influence over their predetermined form. As such, many are uncontrollable sun traps, admitting direct sunshine through the east-facing glass facade in the morning, its replica, the south-facing facade throughout the day, and the identical west-facing facade in the evening.

Without ample thermal storage, these structures overheat during the day. They are inhabitable only with the forced cooling of mammoth air conditioning systems. Unable to retain this heat gain for later use, these structures become cold at night or on sunless days, requiring forced mechanical heating.

The design of a vertical neighborhood addresses the idea of passive solar heating in a tall residential structure.

Design Response to Passive Solar Heating,
Direct Gain

The Building as a Solar Collector

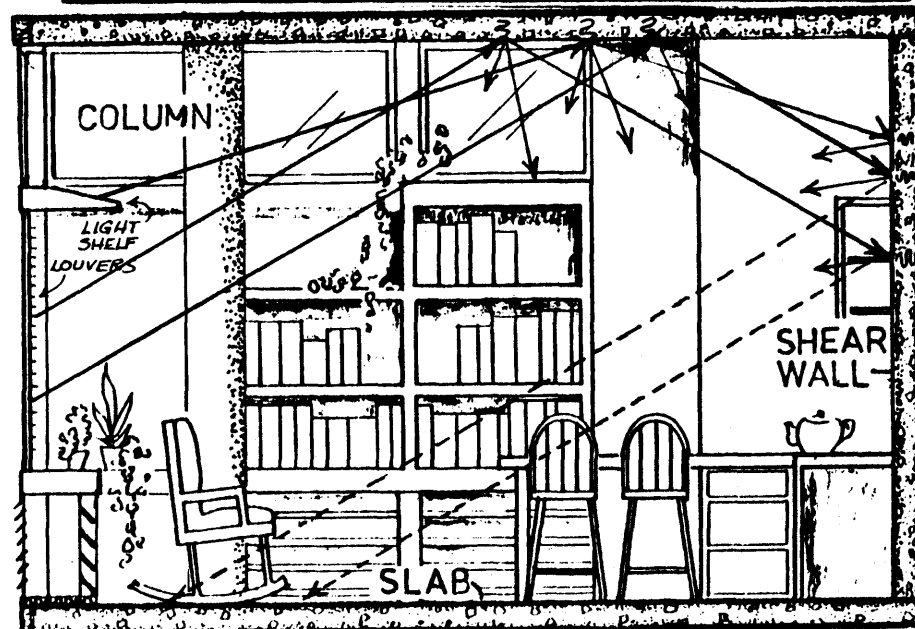
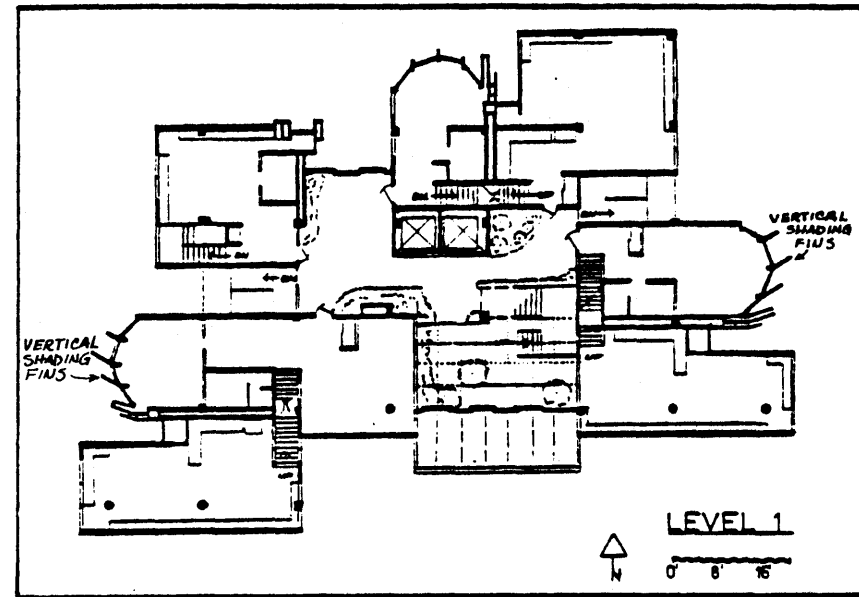
The overall building proportions of 1.0 south-facing to 0.56 east and west-facing allow effective passive solar gain along the 120' south exposure. Oriented squarely to the south, the building relies on the predictable movement of the sun for control of glare and heat.

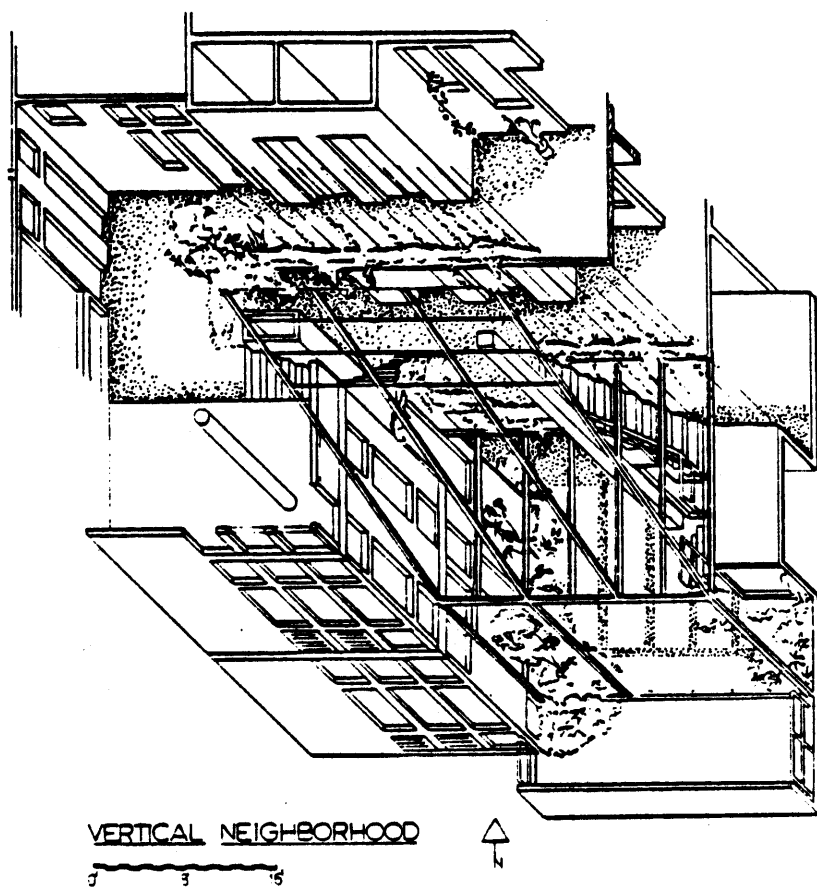
The incoming short-wave solar radiation is diffused at the window plane by reflectorized louvers, light shelves, or multiple reflections off the vertical shading fins. Inside, sunlight is further scattered by reflections off the light-colored interior.

The Building as a Heat Storehouse

The building, itself, is the storage media. The flat plate construction system consists of 8" concrete slabs resting on 18" diameter concrete columns, and laterally braced by concrete shear walls.

With each reflection of sunlight off the interior, light-colored concrete surfaces, part of the energy is absorbed and stored. This is reradiated later as long-wave thermal radiation. The





amount of thermal mass in this concrete structure is sufficient for control of temperature swings.

The Building as a Heat Trap

The entire building acts as a flexible heat trap. With light control louvers as diffusers, sunlight can be obstructed from one space and not from another. In addition, each unit is vented separately, thereby allowing one apartment to rid of excess heat without lowering the temperature of adjacent spaces.

The Neighborhood as a Solar Collector

The three level neighborhood space collects solar heat through a "greenhouse" expanse of south-facing double glazing. 864 square feet of glass along a 28' run of south-facing exposure rises three levels above the lowest level of the vertical neighborhood. This amount of glass admits enough energy to maintain an average interior temperature of 67° on a clear March day.

The Neighborhood as a Heat Storehouse

Close to 5,000 square feet of concrete surface limit radiative temperature swings within the public space to $\pm 4.6^{\circ}\text{F}$. On a clear March day, the

temperature within the public neighborhood ranges from 62.4°F to 71.6°F, a comfortable range for an active space.

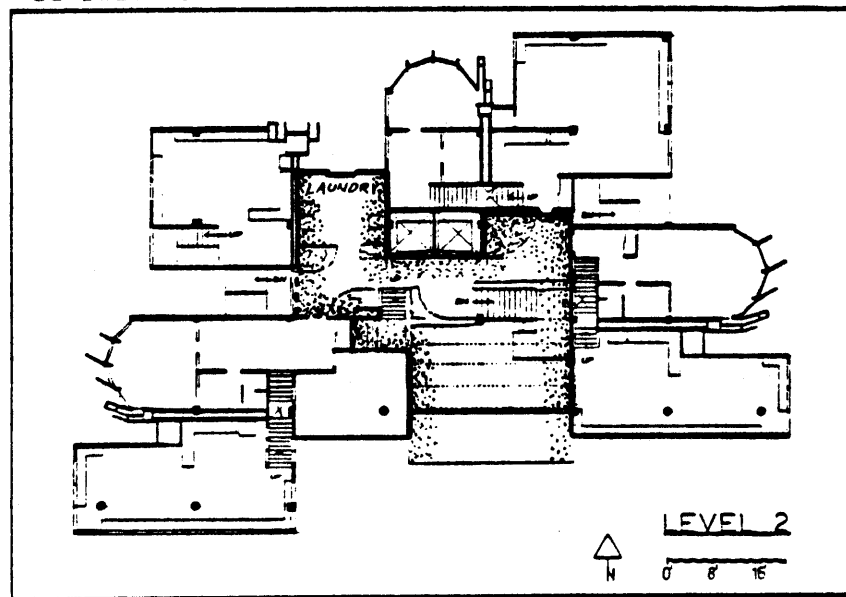
The Neighborhood as a Heat Trap

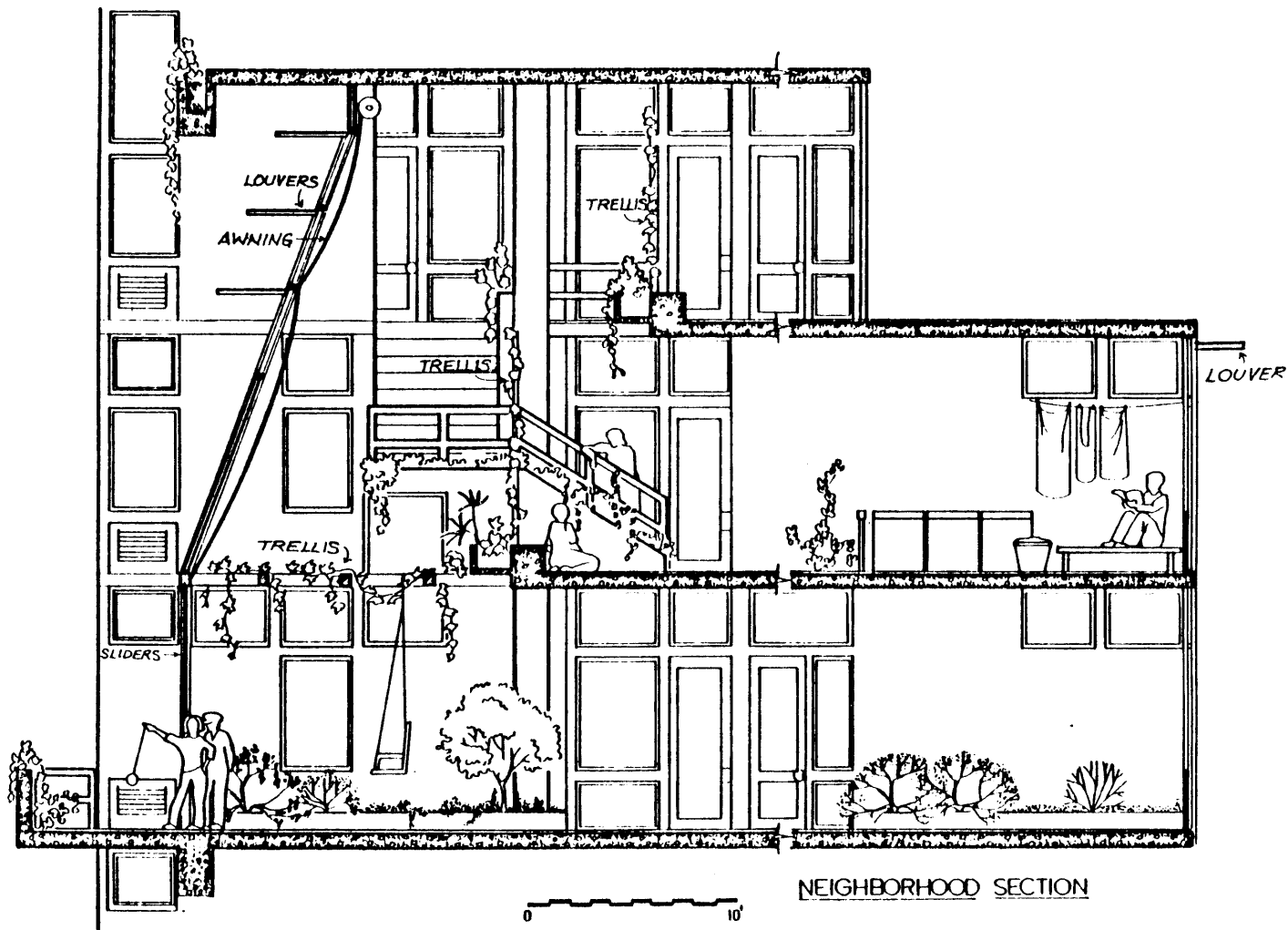
The neighborhood is an efficient heat trap. It is an interior space with most of its glazing to the south except for a narrow two level link with the north side. Heat mirror is used to the north, admitting diffuse northern light while reflecting thermal energy back into the space. In addition, the laundry facility is placed here, an internal heat gain generator that buffers the neighborhood to the north.

Summer sun control consists of a series of festive, cheerful awnings, interior to the space, which prevents the overhead sun rays from penetrating to the thermal mass. They can be opened much of the time; for an interior overhead vine-covered trellis shades the first level of the neighborhood from excess summer sun. Control of glare and overheating on the second and third levels of this public space does not depend solely on these awnings, either. For they, too, are shaded by a vine-covered trellis, extending vertically from railing height to the ceiling. Sun

control with vegetation creates pleasant, sun-dappled expanses of shade, and the neighborhood space shimmers with a sense of summertime.

Seasonal overheating, which can occur without the urgings if direct sun penetration, is also mitigated by the large sliders at the first level of the public space. These sliders open onto a balcony, an exterior extension of the inside/outside neighborhood. Jalousie louvers at the top of the south-facing neighborhood and similar louvers at the north-facing laundry combine with the sliders for effective breezes to carry away unwanted radiant heat.



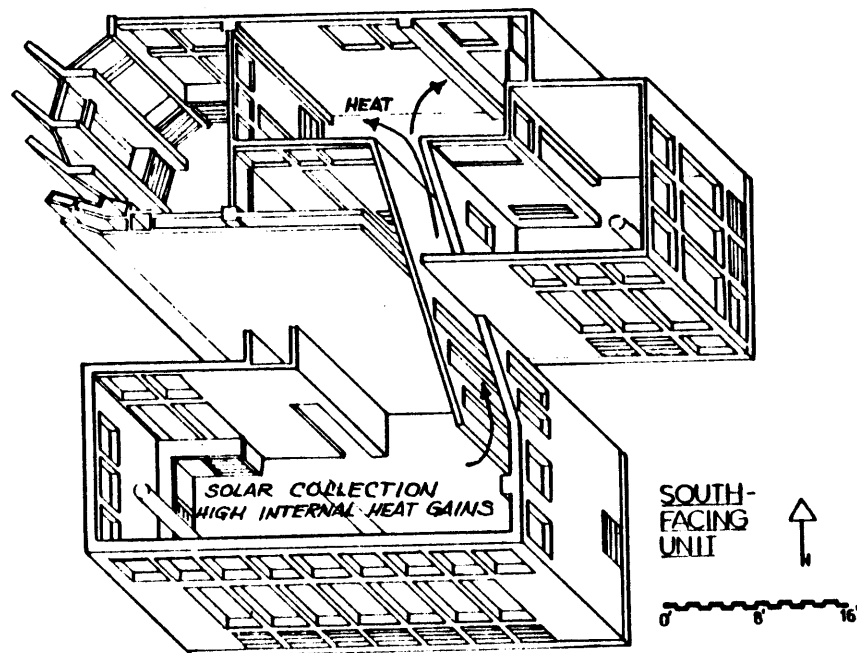


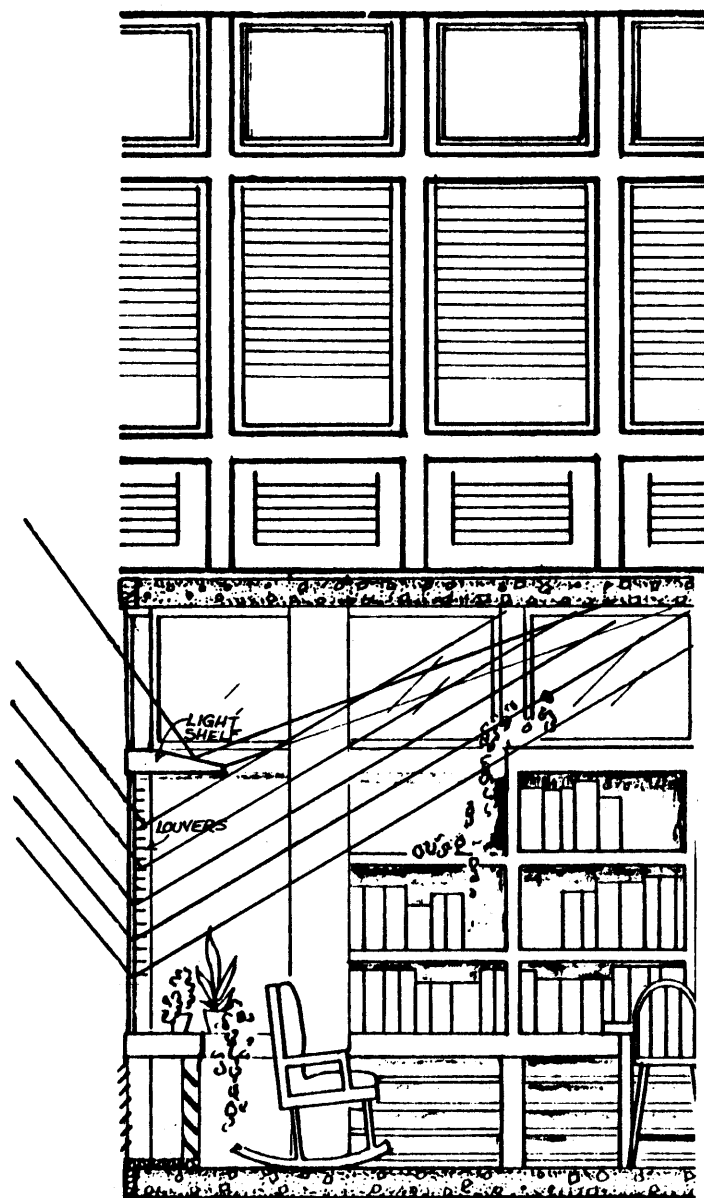
The Unit as a Solar Collector

The typical south-facing unit is 2 bays deep and 2 to 3 bays wide. The south-most bay, the area of solar collection, is one level below the bay that does not see direct south sunlight. This lower level of solar collection is the living-dining-kitchen complex, a zone of high internal heat gains. The auxiliary heating system as well as heat-producing appliances such as a radio, toaster, stove and refrigerator are located at this lower level, supplementing the solar heat gain. Such an organization allows heat from this room of solar collection and internal heat gains to be naturally convected up the stair shaft to the level above. Here it is distributed evenly throughout the spaces.

189 square feet of south-facing glass insures an average interior temperature of 68°F based on clear March weather data.

The window wall, as described in the daylighting chapter, is composed vertically of a clerestory light near the ceiling, a 5'-0" tall midheight window between the clerestory and a ³courting from working plane to the floor for natural ventilation. Sunlight entering the midheight window is deflected upwards 30° by reflectorized light-directing





louvers. In addition to scattering short-wave radiation for distribution to the mass, these louvers are able to deflect unwanted summer sun in order to prevent overheating. An 18" deep light shelf is immediately above these midheight windows, at transom height. It has a slight inward slope in order to toss sunlight entering the clerestory deeper into the room. The light shelf distributes energy to the thermal storage mass, increases light penetration and improves uniformity of light levels within the space. The walls are light-colored, and multiple reflections further distributes the heat energy.

The Unit as a Heat Storehouse

The common core wall and the ceiling contribute 868 square feet of thermal memory. This amount of concrete limits the radiative temperature swing to $\pm 5.4^{\circ}\text{F}$. Excess heat convects up the stair shaft keeping the upper bedroom level in thermal comfort.

The Unit as a Heat Trap

These south-facing units are heat traps. Although each crenelated unit has at least three weatherwalls, ample insulation, tight construction, and double glazing limits the heat loss.

Design Reponse to Passive Solar Heating,
Indirect Gain

The typical north-facing unit has an annual solar heating fraction of over 40% as reported in Appendix A-2. Yet it sees no direct solar radiation other than limited amounts through east or west facing clerestories. Nor does it store heat, for there is no beam component to saturate the thermal mass. Instead, the unit functions as a heat trap. It retains internal heat gains and captures diffuse radiation from the sky vault.

Weatherwalls of high heat resistance and low infiltration, in combination with heat mirror glazing make for an effective heat trap. Heat mirror acts as a selective transmitter of radiation. Short wave radiation from diffuse northern light passes through the heat mirror. The returning thermal energy is not permitted back outside due to heat mirror's low emissivity surface, opaque to the longwave infrared rays. This longwave radiation is reflected back into the space and felt as heat. The north-facing unit not only captures thermal energy from the sky vault, but traps heat generated within the space, itself, about 54,000 BTU/DAY.

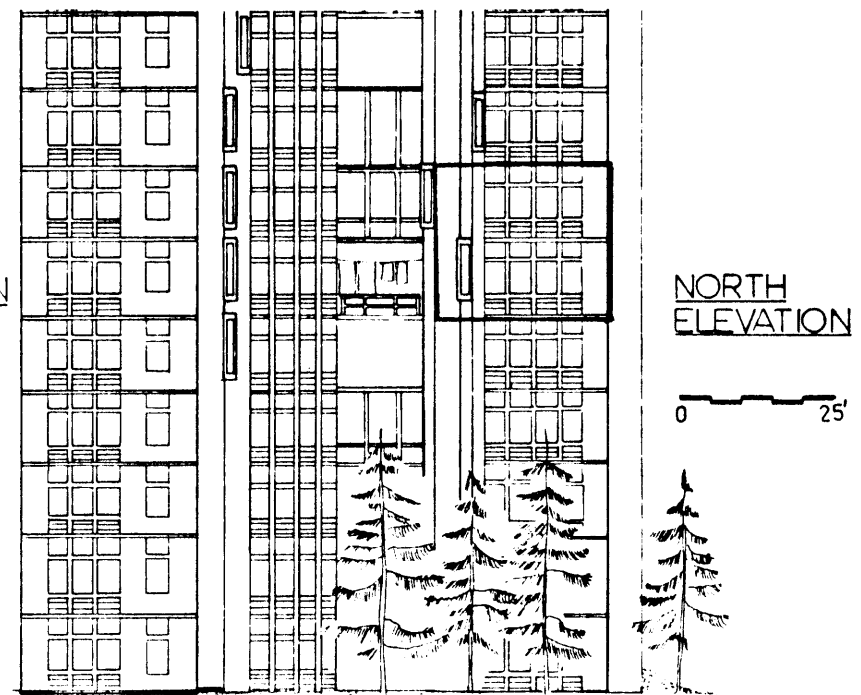
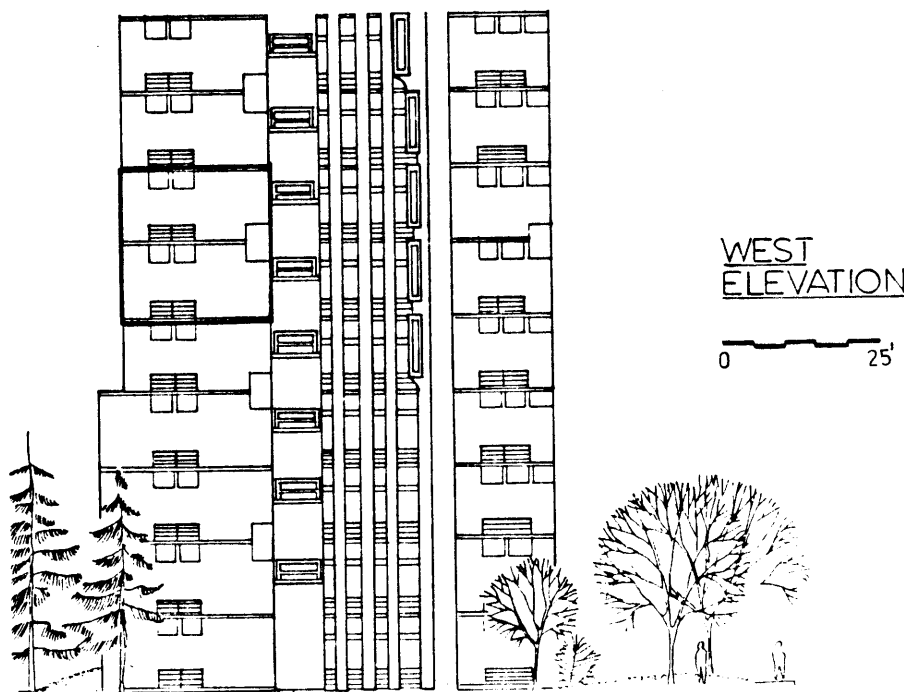
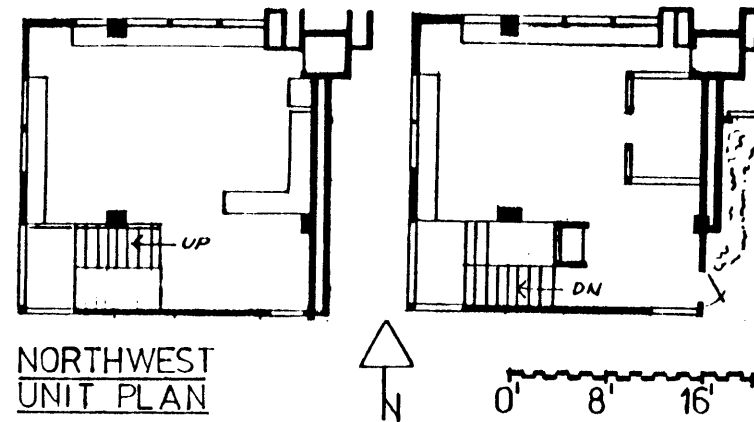
The northwest unit is a stacked two level box with its auxiliary heating system and area of high internal heat gains on the lower level. Natural convection draws the warm air up the stair shaft and distributes it uniformly throughout the upper level.

The effectiveness of passive heating, solar intake/modified building load, is analyzed month by month for this unit in Appendix A-2. The modified unit load is a function of the heat loss per degree day and the number of degree days for each month. The number of degree days for a 24 hour period is the difference between the balance point temperature and the mean outdoor temperature for the day.

Transmitted radiation through heat mirror on an average day accounts for the solar intake. This includes diffuse light from the northern sky and diffuse and beam light from the west.

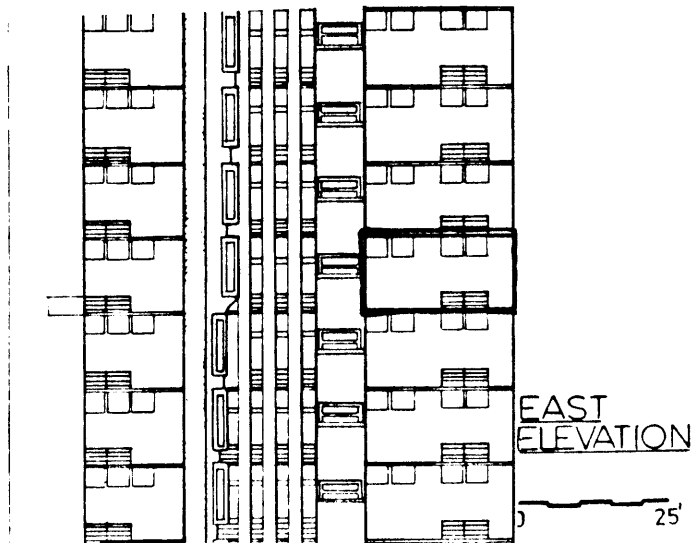
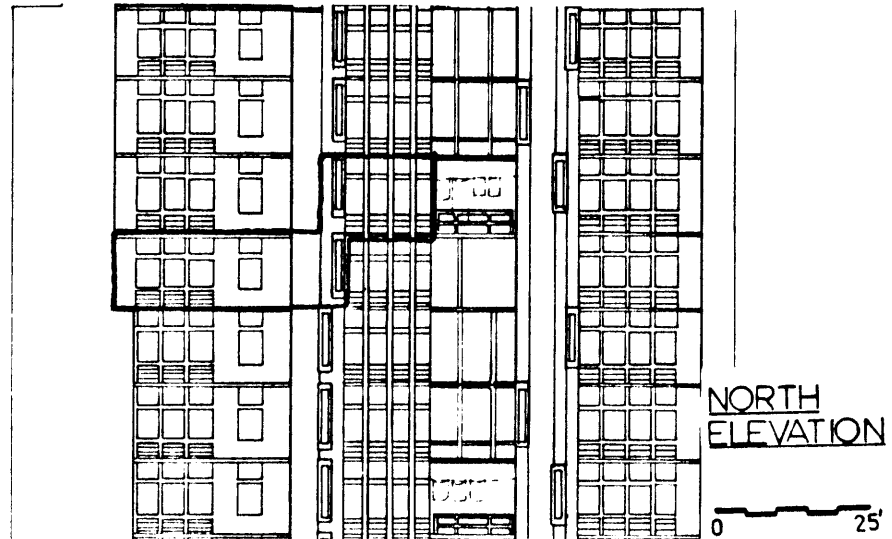
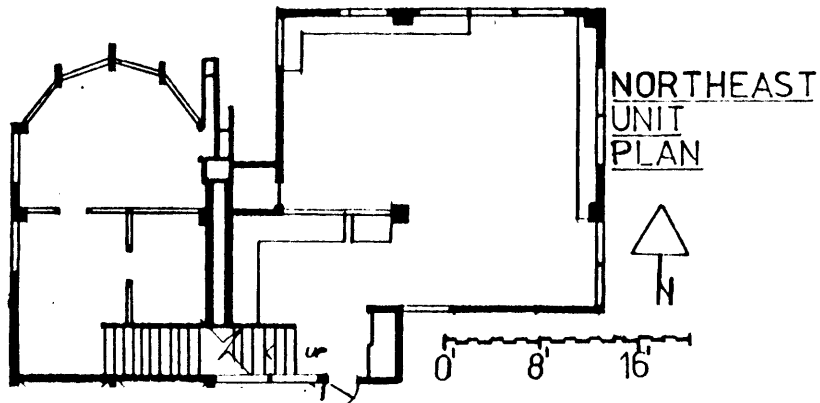
With 47% of the northwall and 15% of the westwall composed of heat mirror, the unit overheats. Decreasing the amount of north-facing glass by 10% and eliminating two of the west-facing

clerestories lessens the tendency to overheat. With 37% of the north wall and 9% of the west wall composed of heat mirror, the unit is 100% passively heated in April, May, September, and October. Passive heating accounts for 27% of the modified unit load in December and January, 39% in February, and 85% in March. The annual solar heating fraction, based on the amount of energy provided by the sun to the annual unit load is 48%.



The northeast unit is a two level staggered arrangement, elongated along its east-west axis. Its auxiliary system and area of high internal heat gains are located on the lower level. The warm air is convected up the stair shaft and distributed uniformly throughout the upper level.

Passive heating for this unit is evaluated in Appendix A-2. 38% of its north-facing facade and 9% of its west-facing facade is heat mirror. The performance of passive heating for this unit is comparable to that for the northwest unit. Solar energy and internal heat gains provide 28% of the northeast unit load in December and January. Passive heating accounts for 40% of the February heating load, 93% of the March load, and 89% of the November load. The annual solar heating fraction is close to 50%.



CHAPTER 3

NATURAL DAYLIGHTING

Why Natural Daylighting?

A shelter designed to capture solar energy for heat also intercepts that portion of radiant energy which permits us to see, sunlight. A solar-tempered building which exploits the sun's "warm" rays while ignoring its "light" rays does not completely utilize the sun's potential. For 12 waking hours per day, on yearly average, the sun offers an overabundance of light, more than required for most visual tasks. And for thousands of years man worked under this natural light in buildings which responded to its availability. Only recently with the advent of centralized, highly controlled energy supplies have buildings disregarded natural light, depending entirely upon artificial sources. Although artificial illumination is needed in a naturally-lit building due to the unreliability of daylight, natural lighting can greatly reduce the use of artificial sources.

The opportunity for conserving lighting energy coexists with passive solar design; the large areas of south-facing glass incorporated for heat gain double as a light source, while the

shading devices guard against both overheating and glare. Thus, optimization of daylight in a solar heated building is conceptually important, if only because light is an inherent part of solar gain, free energy with infinite renewability.

A shelter designed to be cooled by natural ventilation also invites the use of natural daylighting. The opportunity for both occurs at the building perimeter, suggesting a large surface area to volume ratio. In addition, they require openings in the building skin, implying a simultaneous opportunity to conserve cooling, and lighting energy.

Quite aside from the omnipresent energy-related justifications for natural daylight design, people subjectively prefer daylit rooms. (Harvard University Graduate School of Design, "Daylighting"). An obvious factor for this preference is the view to the outside world afforded by most naturally lit rooms. In addition, well-designed daylit spaces avoid impressions of gloom and visual monotony, so typical of artificially lit spaces. In homes where a domestic

atmosphere is appropriate, uniformity of light level appears sterile. Where needed, task lighting creating pools of illumination make the space available for all possible uses.

Natural daylight takes advantage of not only the visible segment of the sun's spectrum, but its intrinsic "living" qualities as well. One such quality of daylight is its predictable recurring cycles of day and season. The lighting within a naturally-lit space fluctuates in phase with these recurring cycles deepening the sense of passing time through contact with the sun, our biological timepiece.

Daylit spaces gain richness through sunlight as it is teased by weather, reflection, and shadow. Exterior light levels can vary from 8,000 fc. in brilliant direct sunlight to 3 00 fc. in diffuse light filtered through dense cloud cover. (Lam, "Daylighting, Alliance with the Sun, Direction not Rejection"). Such variability of outdoor light quality implies a variability of indoor light quality, lending an essential vitality to the perception of daylit space.

Natural Daylighting Objectives

1) A naturally lit residential structure should maximize the area of building that utilizes sunlight without sacrificing thermal comfort;

2) Light and heat should be distributed throughout the space with a reasonable degree of uniformity;

3) The building should provide view for pleasure, for information, for the sense of passing time and for contact with the everchanging conditions outside;

4) Visual comfort should be optimized through control of direct beam radiation to prevent glare; and through control of indoor outdoor contrasts to prevent gloom. Glare at the window should be minimized, as well as contrast between glazing and adjacent wall surfaces.

Limitations to Natural Daylighting in Tall Structures

Limitations are inherent in the natural daylighting of a tall structure. Some of the objectives formerly outlined are not readily fulfilled.

1) Maximizing the area of the building that benefits from sunlight is not a simple task in the design of a tall structure. A conventional multi-story building is a box composed of repetitive layers of smaller boxes lining enclosed corridors or encompassing an elevator core. Due to its lack of differentiation or directionality, the box is often arbitrarily sited in relation to the sun.

2) Uniform distribution of light and heat throughout the space is difficult to achieve in a typical tall building. Only side windows can be used on such a structure, for roof monitors which usually guarantee an adequate horizontal daylight factor cannot be used on the lower levels of a conventional multi-story building. And many sunlit rooms are too deep and have ceilings too low to provide an adequate amount of daylight over the whole working plane. Towards the back of the room,

the general brightness, or scalar factor, of the environment decreases. The dominant light direction, or vector factor, is constant. This causes the vector/scalar ratio to decrease, resulting in the casting of harsh shadows, a modelling of surface textures.

3) The accessibility of views is part of the magic of building to high elevations. Most tall residential structures offer views in one, or at most, two directions from each apartment. Visual discomfort from the high-intensity light in the sky vault may hamper views from tall buildings.

4) The control of direct sunlight to prevent glare and overheating in a tall building is often an afterthought. With a compact design based on geometry, there is no differentiation between east/west facades and those facing north or south. Often interior window dressings are a sad cure for preventable visual discomfort.

The control of indoor-outdoor contrasts is also often ignored, especially in tall buildings where deep rooms align either side of a corridor.

The corridor appears dark in contrast to the glaring patch of sky shining through a window at either end. And the surface mounted luminaries, rhythmically marching down the center of the hallway's low ceiling, do little to lessen the sense of gloom.

Bilateral lighting as well as lighting from windows on walls perpendicular to each other are helpful in distributing daylight to prevent modelling and in washing wall surfaces adjacent to bright windows to minimize contrast. But most rooms in tall structures have only one exposed weather wall. And interior partitions are not designed to allow light to flow from a naturally daylit room to a more interior space. Such living units are, in essence, stacked boxes with 5 of their 6 sides smothered by adjacent boxes, leaving little opportunity for good natural daylighting.

Design Response to Natural Daylighting

The design of a vertical neighborhood explores methods for achieving high quality natural daylighting in a tall building.

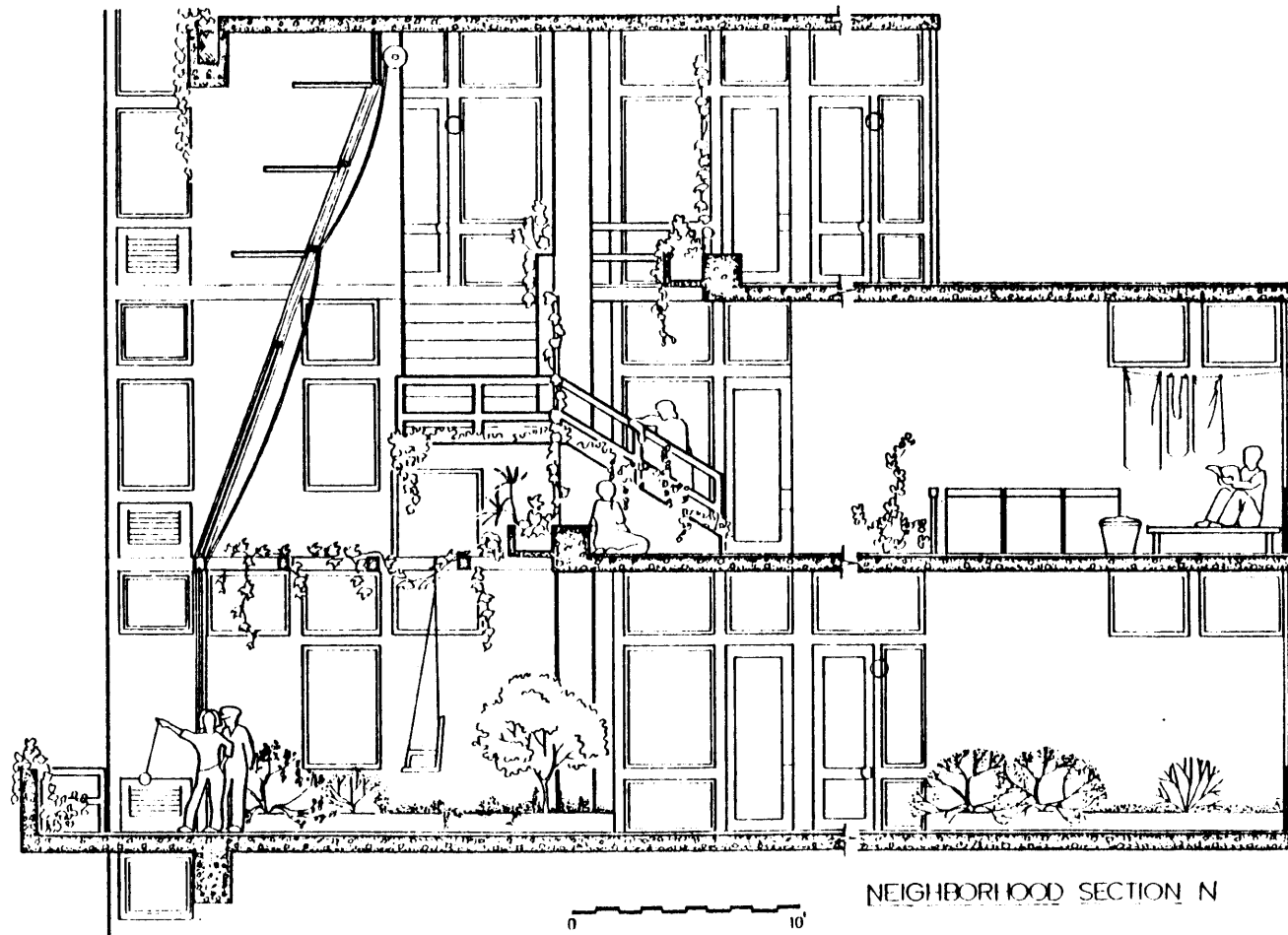
1) Maximization of Access to Sunlight

The overall building proportions of 1.0 to 0.56 elongated on the east-west axis allows direct passive solar gain and maximum access to daylight. Its squarely-targeted south exposure also takes advantage of the predictability of the sun's movement for control of glare and heat.

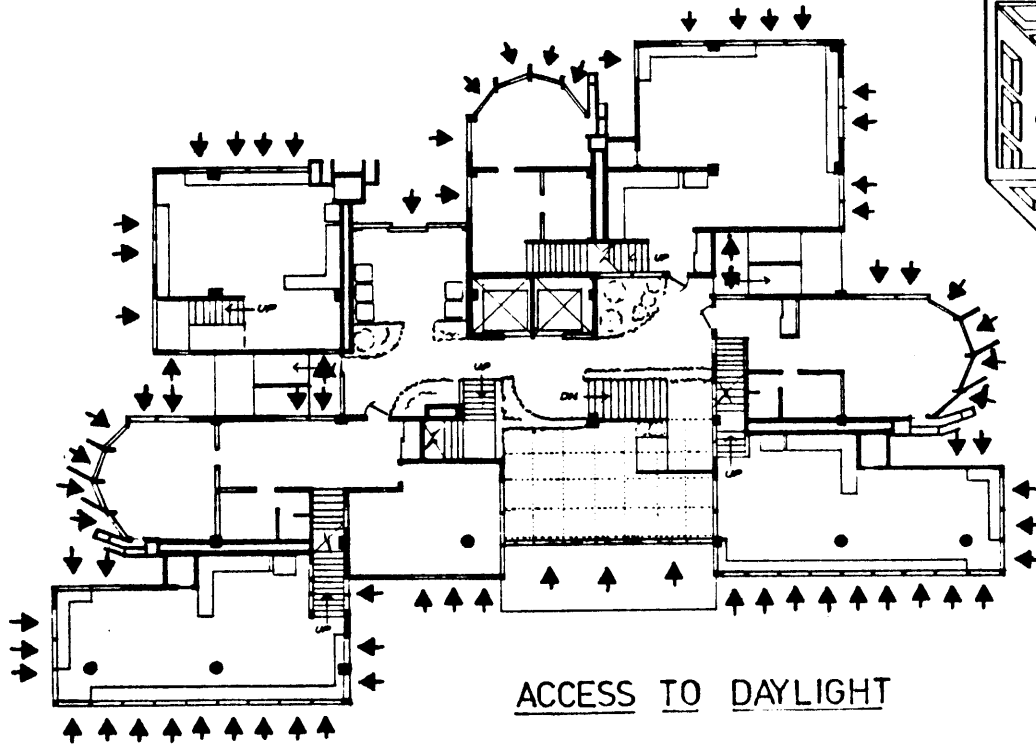
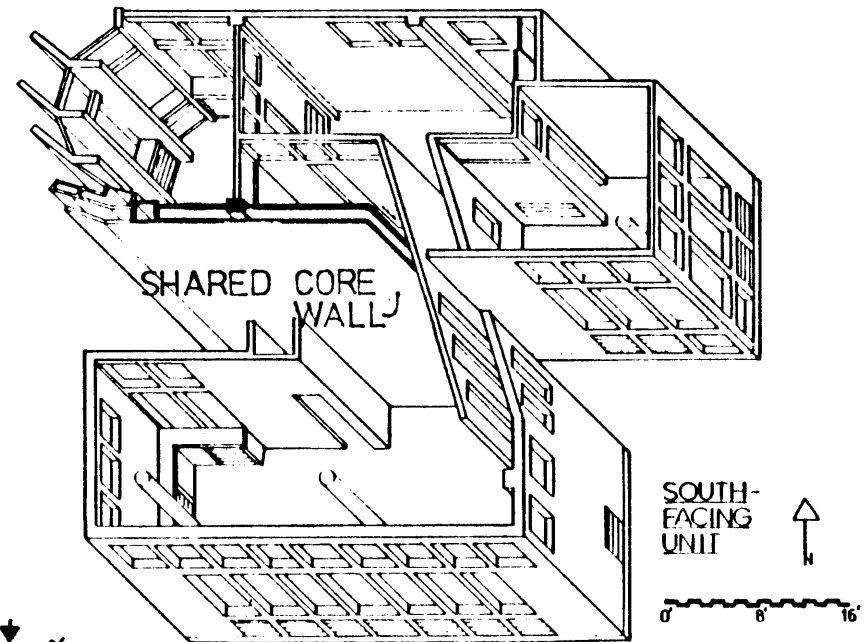
The neighborhood space accepts daylight wherever possible, opening to 3 levels along the south which admits direct shafts of light back to the elevator core from September through March. Additional light is gained through 2 levels on the north side and a small area of glazing to the east and west at the exterior fire stairs.

The architectural detailing of this space is exterior in character, a three dimensional play of concrete, softened with plants, park benches, and porch swings. The space is defined by the entry facade of each unit, composed of a door with an overhead transom, operable windows which accept

light and overlook the neighborhood, a porch lamp, mailbox and accompanying planter for territoriality. Treating the neighborhood architecturally as exterior space enhances the effect of natural daylighting; together creating a perceptual out of doors.



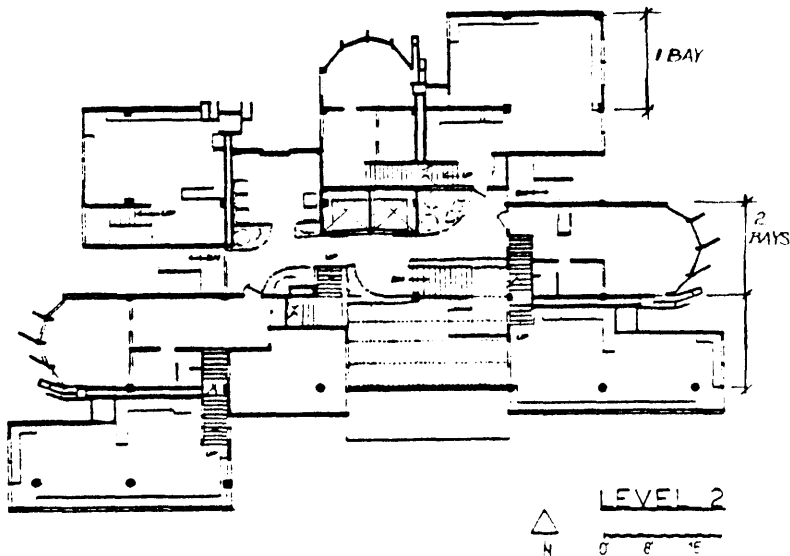
The organization of units around this vertical neighborhood is such that no units are back to back, but rather, draped over each other. The only shared vertical planes are core walls, meaning all other walls are free to admit natural daylight. All units have at least 3 exposed weather walls, maximizing access to daylight.



2) Distribution of Light and Heat

The second objective of natural daylighting, the distribution of light and heat throughout the space is a further refinement of the maximization of building area to sunlight.

Usable daylight penetration in plan is twice the height of the window. (Lam, "Daylighting"). Due to the quantity of surface exposed to the out-of-doors, the deepest dimension from an exterior window to back wall within a unit is 20'. With an 11'-4" ceiling height, the window height to daylight penetration ratio is less than 1 to 2.



High ceilings allow the use of high windows which permit deeper penetration and a more uniform distribution of skylight.

Unlike the south-facing units which are 2 bays deep, north-facing units are only 1 bay deep to better utilize the diffuse skylight that illuminates these units.

The flat plate construction system is sympathetic to the natural daylighting concept. It consists of concrete slabs, 8" thick, spanning 16' in two directions between columns of 18" diameter. This system uses minimum structural depth allowing for a flat, smooth ceiling and additional ceiling height. This improves light distribution and penetration.

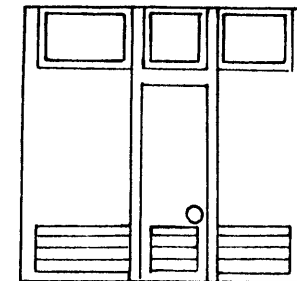
The ceiling remains uncluttered of visual mechanical noise for better light distribution. Natural ventilation and passive heating supplemented by individual gas fired hydronic auxiliary heaters with hot water supply allow the ceiling to be free of piping and ducts. Gas supply, plumbing, and waste disposal are concentrated in the core wall, and also permit the ceiling to be free of piping and ducts for better light distribution. This is difficult to achieve in a conventional tall

structure with centralized heating, cooling, air supply, hot water feed, etc.

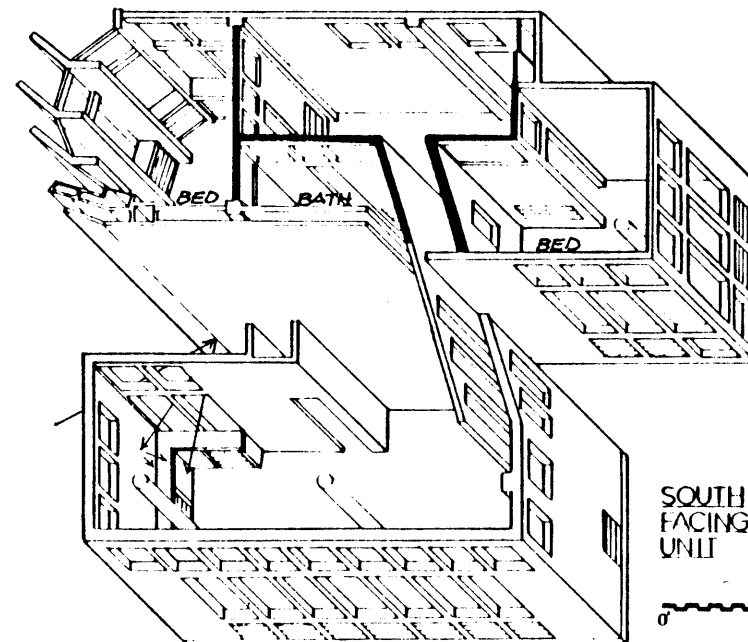
High reflectance matte finishes are used on the walls from working plane to the ceiling making the uncluttered upper portion of the room a very effective light distributor.

With the ceiling serving as a virtual source of daylight, partitioning is kept only high enough to maintain visual privacies. Transoms of single glazing allow maximum distribution of the side lighting from room to room. Partitions, themselves, are kept to a minimum, defining only the bathrooms and sleeping areas. The other spaces flow as one, offering no resistance to light distribution. The effectiveness of the use of such transoms is apparent from the lighting study, Appendix B. The bathroom borrows all of its light from other rooms through these interior windows. It still maintains a daylight factor of 3 to 4%, varying from about 8 fc. on a dark day to more than 40 fc. in hazy sunshine.

Crenellations in plan, where semicircular bays meet the rectangular grid, not only accommodate firestairs and venting systems, but aid in distributing natural daylighting. Light colored

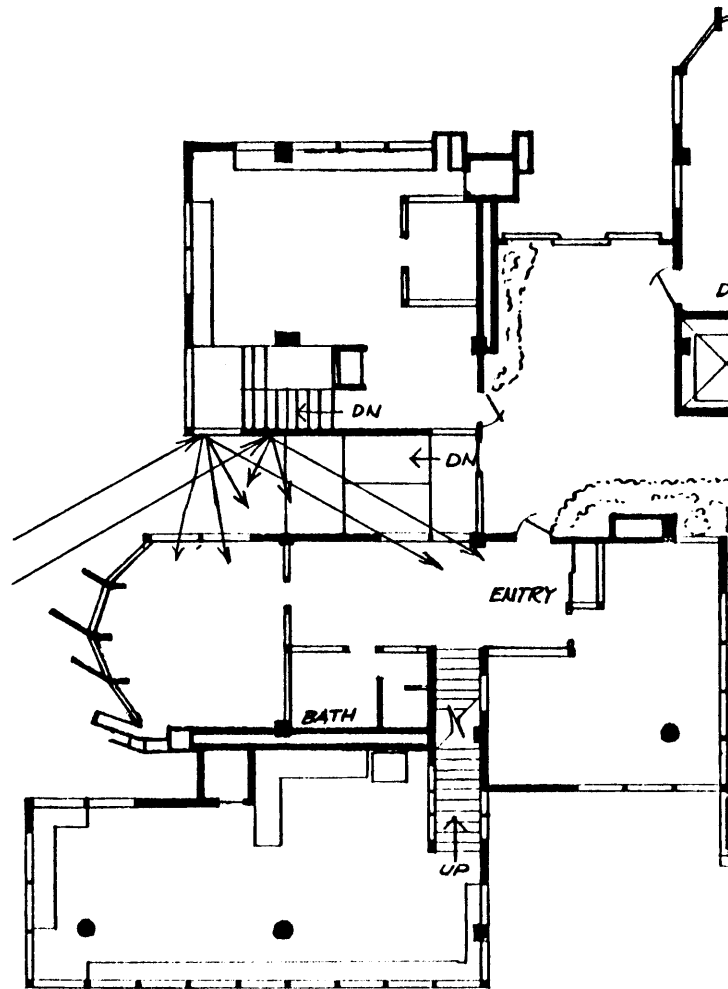


TYPICAL PARTITION



SOUTH-
FACING
UNIT



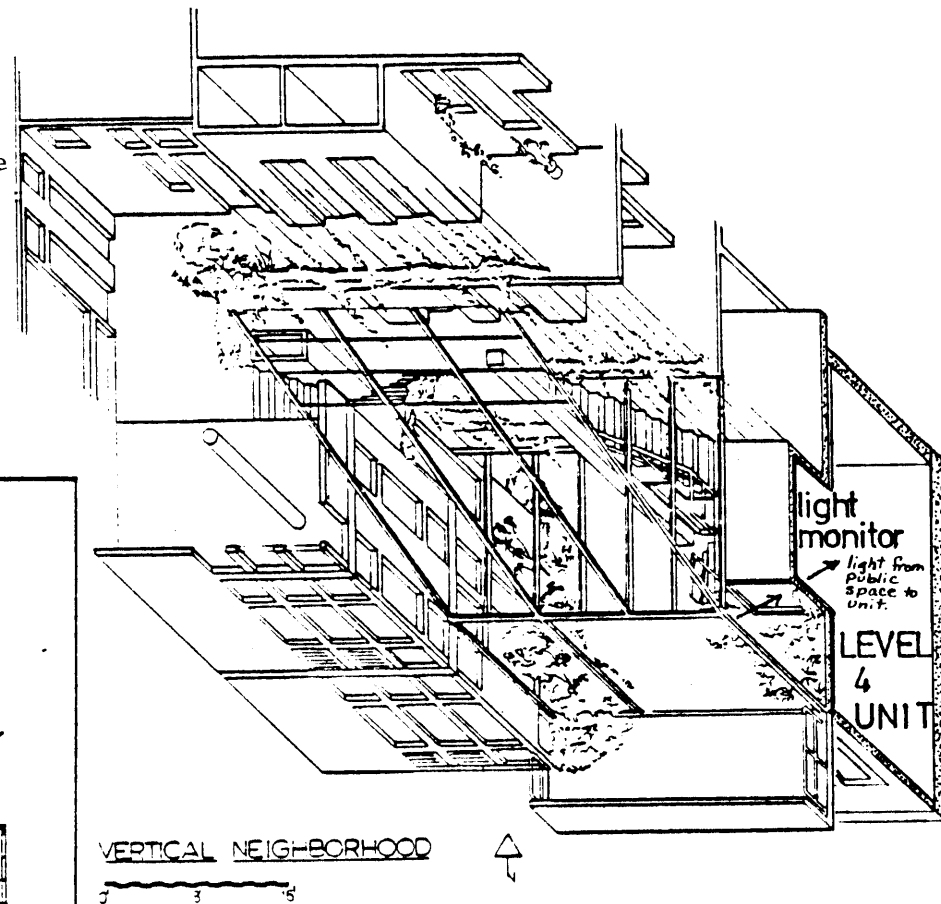
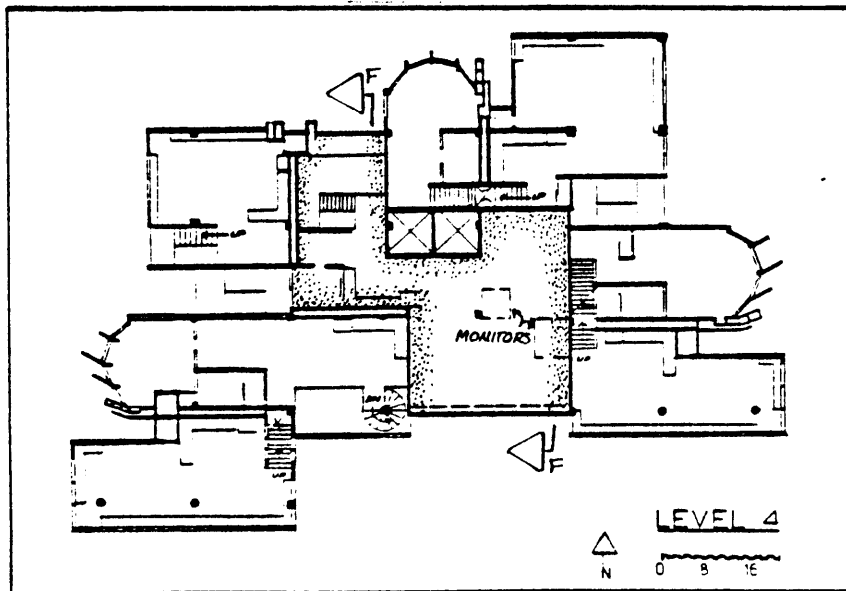


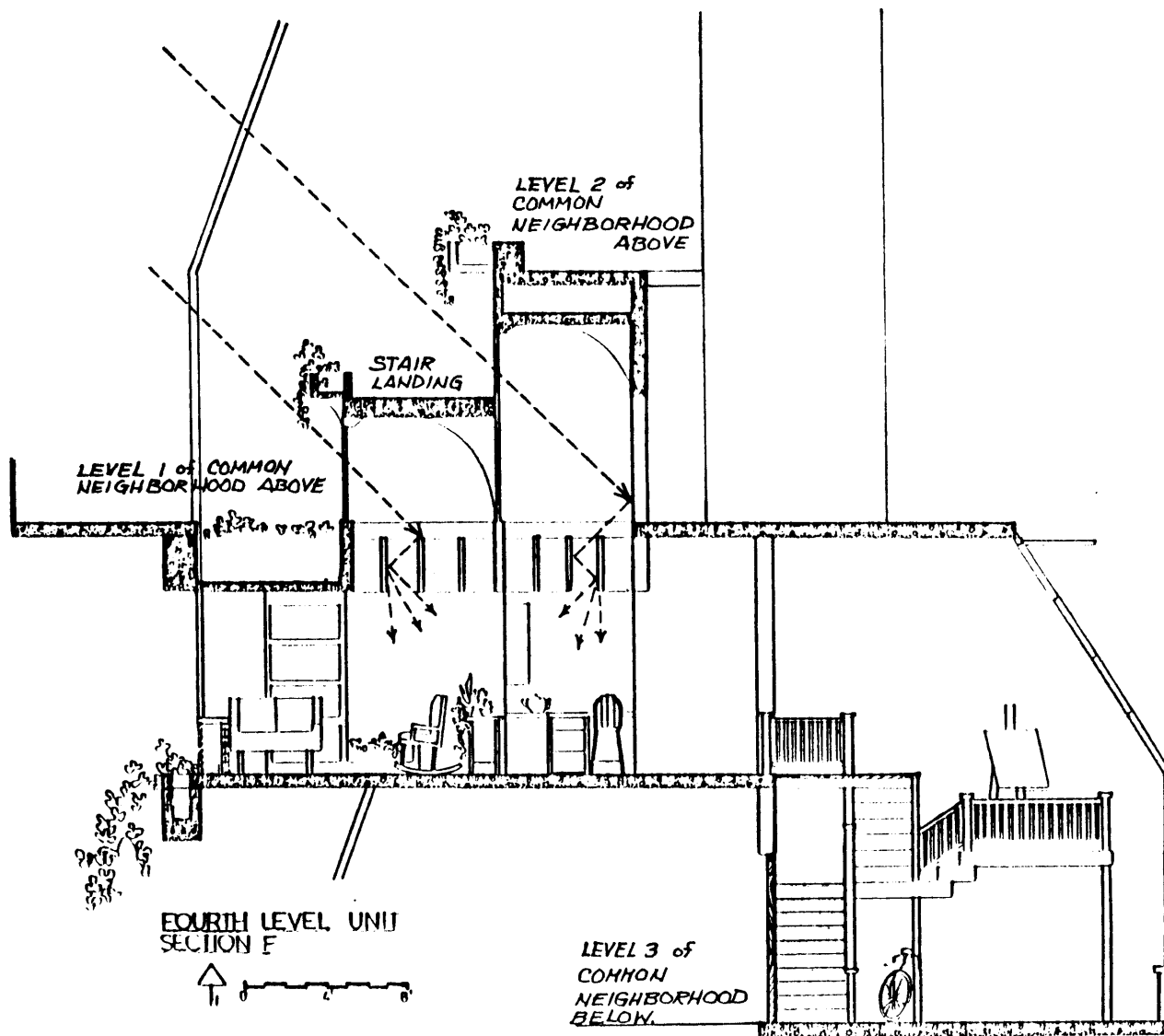
walls of high reflectance face each other. Early morning or late afternoon sun washes the south-facing wall and ricochets to the north-facing wall, entering glazed openings to aid in lighting this potentially dim space. A light model built of this particular area is used to test the effectiveness of this occurrence as reported in Appendix B-5. On a sunny March afternoon, 28% of the daylight in the entry, and 47% of that penetrating the bathroom is reflected light from the exterior north wall. This is a substantial amount of light, especially in spaces of relatively low light levels.

The limitation of using only side windows is adhered to in most of the dwelling units. The unit on level 4 which vertically separates one public neighborhood space from another has limited exposure to daylight. Although it has over 20' of south exposure, the unit is tucked under the protruding neighborhood above, thus reducing the diffuse skylight and direct solar gain from March through September. The space is further dimmed by a dropped beam above, spanning the column-free neighborhood space.

With the roof of this particular unit serving as the floor of a well-lit "outdoor" public space,

penetration through this plane will yield the unit some natural daylight. A logical place to perforate the "roof" is under the public stair, an area of otherwise wasted space. This south-facing clerestory monitor gains light from the public space and reflects it down to the unit. The planter in front of the clerestory is sunk to the depth of the transfer beam and furnished with a top layer of white gravel for greater light reflection. Even during the summer months when direct sun is not to be had in this space, the clerestory monitors serve to transfer daylight from the public space to the unit below.



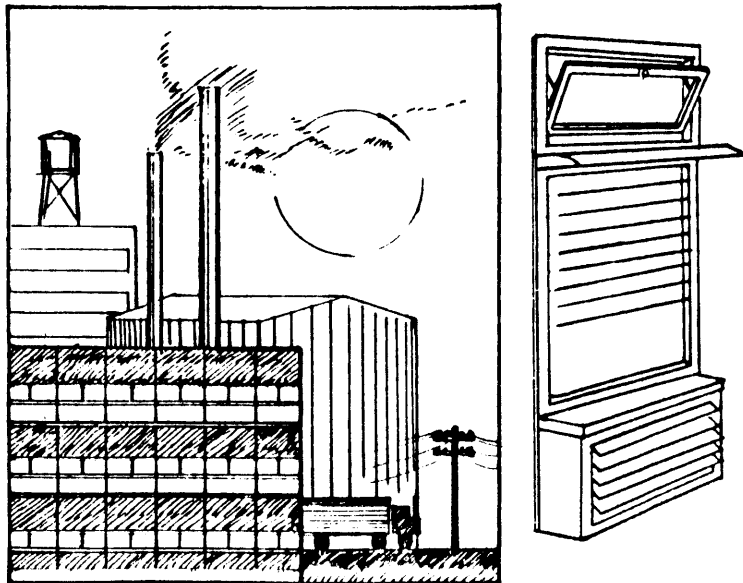


3) Provision of Views

The third objective of natural daylighting is the provision of views.

A tall window height has already been specified for its light distribution, penetration and uniformity attributes. But the rest of the window wall has not been defined.

One very important function of windows in tall structures is to provide a visual link to the world outside. Different portions of the window contribute different information, for the view is stratified horizontally from a layer of



ground, to a layer of horizon, to a layer of sky.

The lowest level is very important in tall structures, as a view to the ground conveys information about activities immediate to the base of the building. Although a seemingly limitless band of windows at floor level in a tall structure provides visual connection to the activities below, it denies a sense of ground and horizon local to the room. This results in a feeling of instability, the feeling of standing at the edge of a roof with no railing. Allowing only occasional views to the ground below ameliorates this problem. And defining the low window height around the rest of the room's perimeter with darker walls, opaque louvers, or wainscoting helps to contain the space, much as a sturdy railing or parapet wall does on a roof.

A view of the skyline is also desirable. Above this, lighting criteria is the only reason to extend the window head higher.

This suggests dividing the wall into three zones, the top few feet serving to distribute the sky light uniformly and with deeper penetration into the space. The midheight window provides view of the skyline and, like the clerestory, is a

significant collector of light and heat. When light and heat are not desirable such as on the west side or at selected areas on the south side for the control of overheating, this zone becomes wall area of highly reflective matte finish.

The natural ventilation criteria demands an insulated louver system below the working plane. This course establishes a local horizon and can be broken at selected points for a downward view to local activities at the ground.

The criterion for view (as well as that for light distribution and minimization of contrasts) requires the unit to face many directions for a variety of visual links. Direct gain passive solar design insists on south-facing windows for heat gain. Often north-facing glazed areas are shunned in trepid fear of heat loss. But heat loss can be decreased through the use of heat mirror.

Windows facing north often offer the most pleasing view, being sunlit from behind the observer. On clear winter days, the low sun shining from the south drenches the entire scene to the north in golden light illuminating the vertical planes of buildings and trees. The low altitude angle of the sun casts definite shadows of even the

most subtle details, making the south-facing landscape highly readable, almost surrealistic. With cloud-laden skies, the intense three-dimensionality of the sunny north-facing view flattens. In the diffuse, dim light, the scene takes on the aura of a primitive painting, building facades becoming soft-toned planes and trees as brush marks silhouetted against the snow-covered ground.

This design, being highly three-dimensional, permits each apartment to turn in many directions, the typical unit facing each of the four cardinal points. These windows provide not only outlooks to the exterior world, but visual access to the neighborhood space as well.

4) Optimization of Visual Comfort

The success of the first three natural daylighting objectives, maximization of building area utilizing sunlight, distribution of that sunlight, and provision for views, is contingent on satisfying the fourth objective, optimization of visual comfort. Access to sunshine and views is not pleasant in the disabling glare that can occur if visual comfort is not achieved.

Control of direct beam radiation to prevent glare and overheating necessitates refinement to

the window wall design formerly described

Expanses of south-facing glass sized for winter solar gain need shading in summer to prevent overheating. An overhang can control summer sunlight; but this is unadvisable as climatic seasons lag behind solar seasons. In addition, an overhang decreases diffuse daylight penetration near the window as described in the lighting study of Appendix B-1.

Many passive solar structures employ adjustable overhangs that can be regulated to shade during the warm autumnal equinox yet admit full sun on a wintry March day. The use of adjustable shading devices or vine-covered trellised overhangs on a tall structure is precluded by wind speeds several times that of ground wind and unpredictable turbulence. In such a potentially harsh environment, interior horizontal blinds can serve to control both light and heat. The light level in a room with louver sun control is as much as 40% higher than the light level in a room with an overhang. This is reported in Appendix B-2.

Reflecting louvers are able to direct insolation to the white ceiling, diffusing the light and distributing the accompanying heat throughout

the concrete structure for thermal storage. The louvers reflect at a 30° angle to the horizontal, throwing light above eye level, thereby reducing glare from direct sunlight as well as decreasing high luminosity at the window. With a spacing to width ratio of 1 to 1.9, the louver cross section is of an arc that accepts variation in solar profile angles without frequent readjustment (Johnson, Benton, Hale, Kramer, "MIT Solar Building 5").

The louvers can be closed for night privacy or adjusted to reject summer heat. On cloudy days, when shading is not needed, they can be raised, increasing the amount of diffuse daylight entering the room and improving viewing conditions.

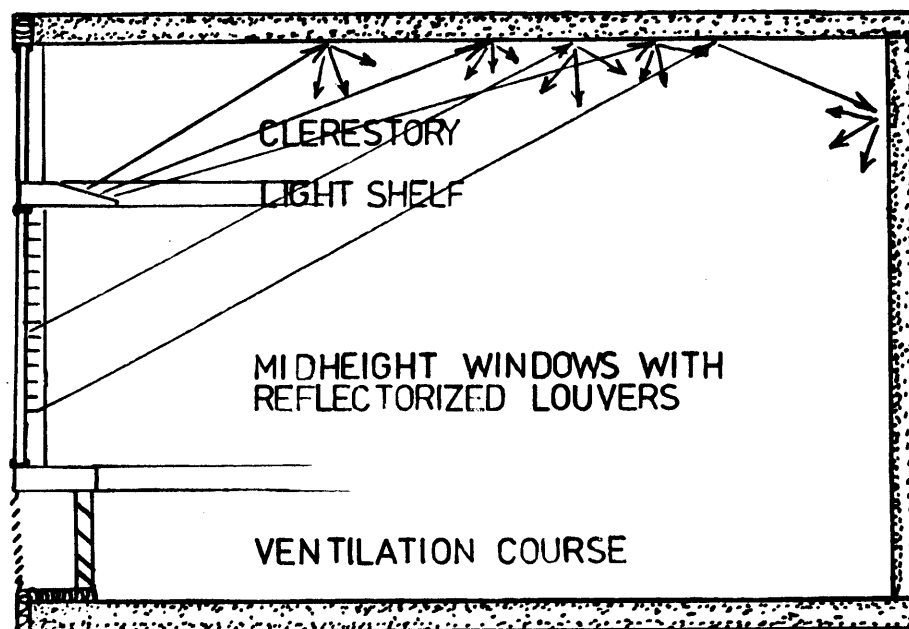
Although louvers seem well suited for the non-operable midheight windows, they seem less amenable as a sun control device for the windows above transom height. These windows serve for light penetration, distribution, and uniformity. Here the average distance of louvers from the ceiling is less, meaning a shallower penetration of light. A light shelf with a mirrored reflector, however, is dropped farther from the ceiling deflecting light deeper into the room. This effect is readily seen in Appendix B-3. The light shelf intercepts light

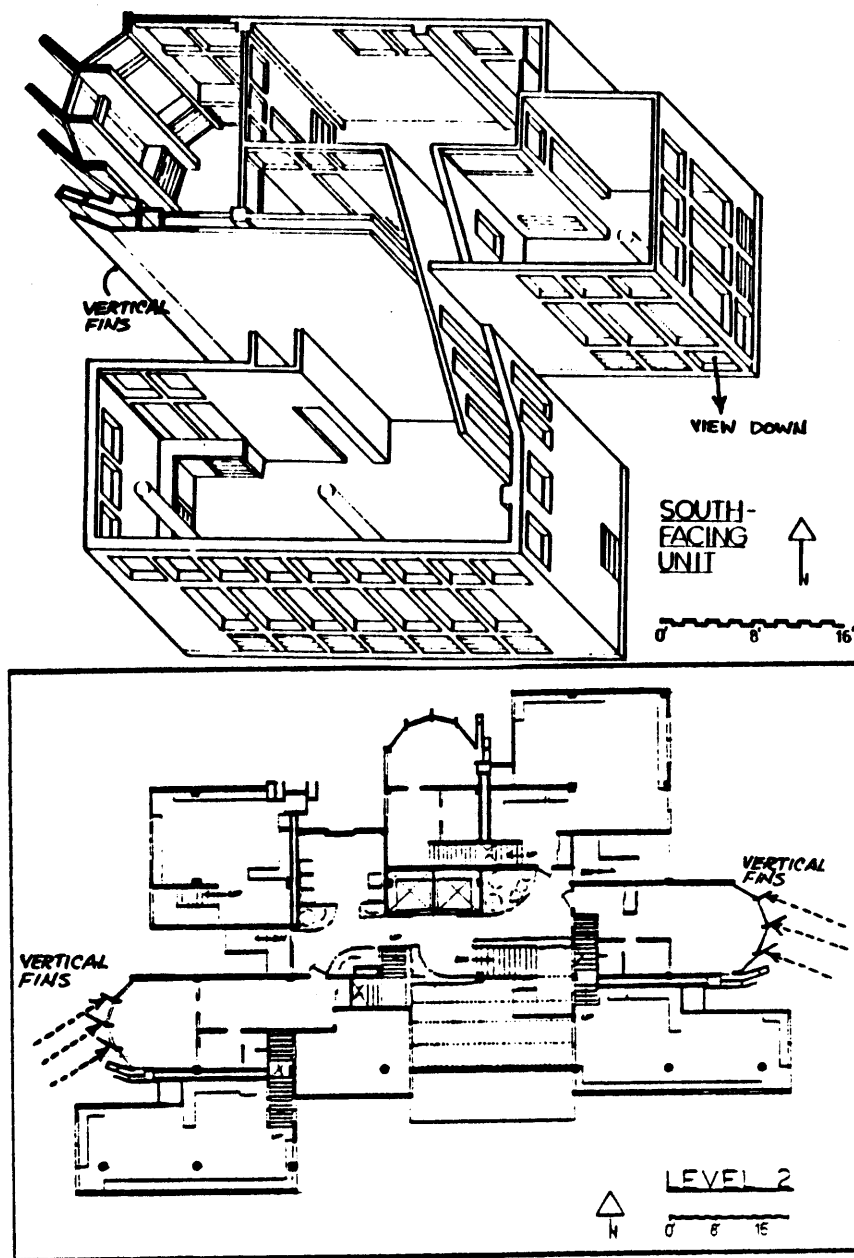
at the window plane and deflects it towards the ceiling in the back of the room. This lessens the light level at the window slightly. In combination with the adjustable blinds dressing the mid-height windows, almost uniform distribution of light can be achieved. In addition, the light shelf reduces glare by deflecting the light over occupants' heads.

The clerestory is composed of hopper windows for air circulation above living zone. Opening inward so as to not be caught by the wind, they work well in combination with a light shelf. Louvers interfere with this function, vibrating noisily in a breeze.

The light shelf reinforces the architectural break between the south-facing, light distributing clerestory and the midheight window, which offers view. This horizontal line wraps around to the interior partitions, marking the transom sill height.

And finally, windows are rarely allowed to punctuate the lowest coursing of wall. The only function of these special windows is view, and they are so limited in number and area that sun control is not a critical issue. Their vertical position





on the wall is well below eye level, even when seated. And with floor covering or carpet on the floor, reflected glare is unlikely. Along the east and west exposures of the rectangular elements in plan, the midheight and lowest coursing of windows are eliminated with three clerestories providing light to the room from this direction. The elimination of the midheight windows prevents glare and overheating problems from low altitude angles of the setting sun.

The rounded bay form of the bedroom upstairs depends on east or west exposure for daylight access: its south wall is the shared core, and exterior fire stairs consume part of the north wall.

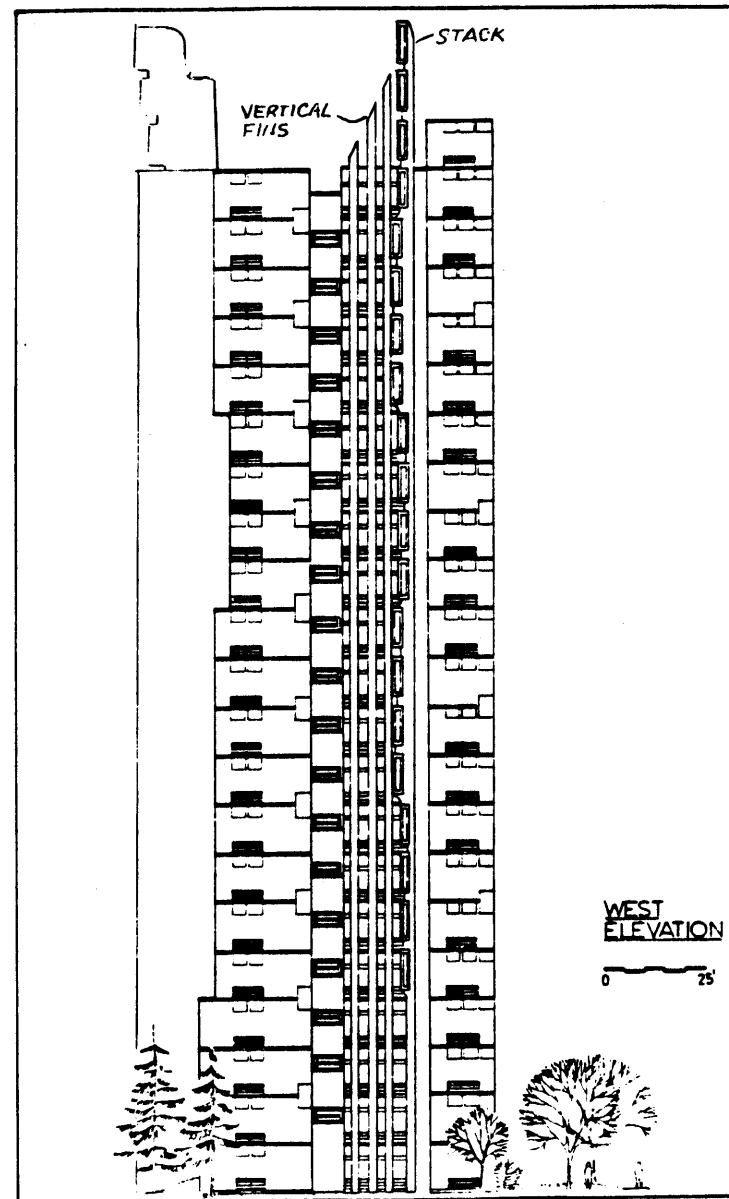
In plan, the semicircular shape causes many of the low sun angles to glance off the windows. But with the sun setting to the south of west in winter, straight on course during the equinox, and to the north of west in summer, each of the angled windows admits direct sun at some time of the year.

Adjustable vertical louvers are eliminated as a viable shading option due to the unpredictable wind patterns at this height. Alternatively, four building-sized vertical fins are designed, some of which serve as stacks for natural ventilation.

Oriented 35° to the north of west, these fins are repetitive, strong, vertical elements that rise uninterrupted from building base to sky. Constructed of light-colored precast concrete, these fins reflect much of the striking sunlight, and through multiple reflections the west-facing room is amply daylighted. A daylight factor of .19 is achieved, as seen in Appendix B-4.

The effectiveness of these fins as sun baffles is determined by simulating critical sun angles. A beam of light is projected to a model mounted on a heliodon, as recorded in Appendix C. From September to March, no shafts of light penetrate the space, yet light levels within the space remain high due to the reflective matte surface on these fins. In the worst condition, June 21, around 6 A.M. and 6 P.M., two of the windows see 25% shading. Since the summer sun has a high trajectory until immediately before it sets, problems of glare are reflectively short-lived.

One hour earlier, sun penetration is limited to a rather pleasing pattern of very narrow light shafts through each window. Even at 6 A.M. and 6 P.M., there may not be much problem with glare and heat gain, for at this low angle, the sun's



energy must penetrate a thick layer of atmosphere before reaching the window. Any problem is easily controlled with interior window dressing.

Another aspect of visual comfort is the control of contrast between inside and out as well as the minimization of contrast between glazing and adjacent wall surfaces.

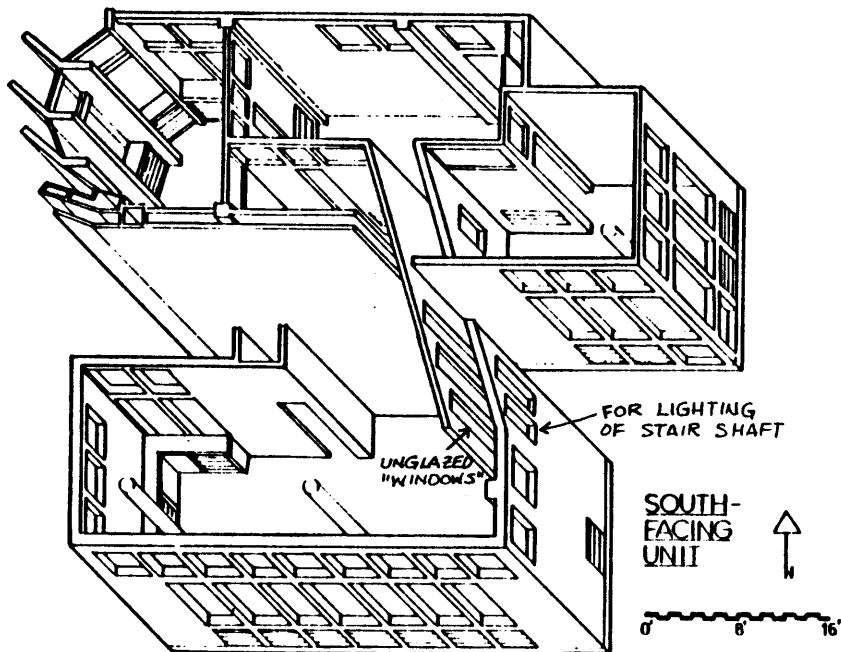
In a room lit by side windows, not only is the illumination indoors perceived, but also the interior illumination in relation to the exterior. When outdoor illumination changes, the indoor illumination changes proportionately and the contrast between interior and exterior luminances will remain constant. The illumination at a point indoors can be expressed as a percentage of the horizontal illumination at that moment under an unobstructed hemisphere of outdoor sky. This is valid only when the pattern of sky luminance is unchanging, when the weather is overcast. On sunny days or partly sunny days, the fraction of indoor to outdoor illumination will no longer be a constant.

Daylight factor recommendations listed in Appendix D ensure that when a building is naturally lit with no supplementary artificial lighting, the illumination levels on the working surface will meet

the requirements of the activity for most of the working day and that the visual environment will be comfortable. The building will appear to be well lighted in relation to the exterior light level, provided that the room surfaces are of sufficient reflectances.

No quantitative boundaries are set on a related issue, sky glare from windows. People are more tolerant of glare from transparent side windows than from artificial light sources due to the effects of "proximity" and "habituation." The "proximity" effect is the idea that an expanse of glare immediately overhead feels more oppressive... almost intimidating... than a distant source of the same luminance much further away, the sky vault. The "habituation" effect is the idea that people are used to glare from the sky and expect it, while an artificial light source of the same luminance is intolerable (Lynes, Principles of Natural Daylighting, p. 154). Nonetheless, control of indoor-outdoor contrasts (daylight factor) and minimization of discomfort glare is necessary.

The crenulated building form with its high surface area to volume ratio and the organization of units permit most spaces some degree of



bilateral lighting. The value of light entering the space from many directions can be seen from the light study, Appendix B-4. This appendix compares values of light levels and daylight factors with and without the contribution of various windows. Light entering the front, back, and sides of rooms slightly increases the daylight factor. The effect is almost negligible, however, in the shallow well-lit south-facing rooms where most of the light is obtained from the windows so designed for admitting insolation. In fact, the east-facing clerestory windows on the lower level seem to do no more than to sidelight the stair shaft. These east-facing windows are balanced by the unglazed "windows" overlooking the kitchen-dining-living area.

The positive effect of side lighting on daylight factors is more pronounced upstairs in zones of lower light levels. 35% of the natural daylight at the unit entry is contributed through side windows as much as 32' away. It is in these low-light level zones that multidirectional lighting prevents excess contrast causing gloom.

A real value of multidirectional lighting is its mitigation of the contrast between bright sky and adjacent wall. Each window wall is painted

white and reflects light from glazing in an adjacent wall, lessening window-wall contrast, thereby lessening gloom.

Multidirectional lighting also aids visual comfort by decreasing the vector/scalar ratio in the back of rooms. A single illumination vector at a point in space represents the dominant lighting direction, a maximum vector occurring with light entering from only one direction. This results in the casting of harsh shadows, a modelling of surface textures. Multidirectional lighting lessens the dominance of the vector, decreasing this modelling effect.

Window dressing is important in decreasing discomfort glare at the window. The midheight retractable horizontal louvers on the south-facing facade as well as the lightshelf at clerestory height help to shield the window from such glare. On the east- and west-facing facades, the permanent vertical fins act as giant splayed window reveals to control the contrast between the bright sky and adjacent wall surfaces.

CHAPTER 4 NATURAL VENTILATION

Why Natural Ventilation?

The arguments in favor of passive solar heating and natural daylighting are equally applicable to natural ventilation. Natural ventilation is an opportunity to reduce environmental degradation, to conserve energy, and to avoid manipulation by governments and industries who monopolize these energy supplies.

The pressure and thermal forces necessary for dynamic movement of air are as universal and free as sunshine. A solar tempered building, designed to utilize the warmth and light of the sun, should also use the sun's energy for inducement of air movement. The potential of natural ventilation coexists with passive solar heating and natural daylighting. The opportunity for all three occurs simultaneously at the building perimeter, implying a large surface area to volume ratio and multiple openings in the building skin.

Natural ventilation criteria can give meaningful form to architecture. The need for natural ventilation varies with geography and climate; and like passive solar heating, it can lend a definite character to regional styles.

Natural ventilation provides a link to the

world outside, important for the outdoor character of the vertical neighborhood. Cooling breezes, in combination with heat from the sun, natural daylighting, a profusion of plants, and exterior architectural treatment of unit facades makes this a convincing outdoor space.

Natural ventilation is used in most domestic settings. An apartment within a tall residential structure is perceptually more homey with operable windows. Proper natural ventilation requires adjustments to window openings such as jalousie louvers, hopper windows, or inlet louvers to a ventilation stack. Such activities alert people to their own environment and building. More importantly, natural breezes supply fresh air and aid in the evaporative cooling process. A building designed for adequate continuous air movement through natural economic means greatly adds to human comfort during the hot summer months.

Natural Ventilation Objectives

1) The building should be located in the free sweep of the wind. (Caudill, Some General Considerations in the Natural Ventilation of Buildings, p. 28).

Before any efforts are made to design for natural ventilation, the wind must flow to the building. If trees, hills, or buildings divert the flow of air, the wind shadow behind the obstruction has little air flow. This low pressure area is not a good place to build, for there is no prevailing wind to exploit. Natural ventilation, in this case, depends on draft due to pressure and temperature differentials between a low level inlet and a high level outlet.

2) The building should be designed with consideration given to high pressure areas and wind shadows in order to facilitate the flow of air through it. (Caudill, Some General Considerations, p. 28).

This suggests a building orientation with maximum wall area perpendicular to the wind. This wall, facing the high pressure area, should have inlet openings through which air is forced due to pressure exerted on the wall. Effective air flow within the building requires outlets in the low pressure walls so that air can be "pulled" out of

the building. Low pressure walls occur on the leeward side and on surfaces perpendicular to the windward source. If the building orientation is predetermined for solar heat gain and natural daylighting, consideration to high and low pressure areas should still occur.

3) The direction of air flow should be controlled by proper location and design of buildings. (Caudill, Some General Considerations in the Natural Ventilation of Buildings, p. 32).

The air flow pattern within a space is controlled by wind direction and high and low pressure areas. It is also controlled by the placement and design of inlet openings.

Air tends to flow along surfaces. If the inlet is close to a side wall, it enters the room at an oblique angle. If the inlet is adjacent to the ceiling, the fresh air hugs the ceiling. Inlets should be installed at a low level if air flow near the floor is desired.

Windows designed for summer cooling should divert the air flow within the "living zone." Windows designed for winter ventilation or overhead airflow should deflect incoming air flow upward to mix with the warmer air in the upper portion of

the room. Windows designed to fulfill both summer and winter ventilation needs should be capable of directing air both downward and upward.

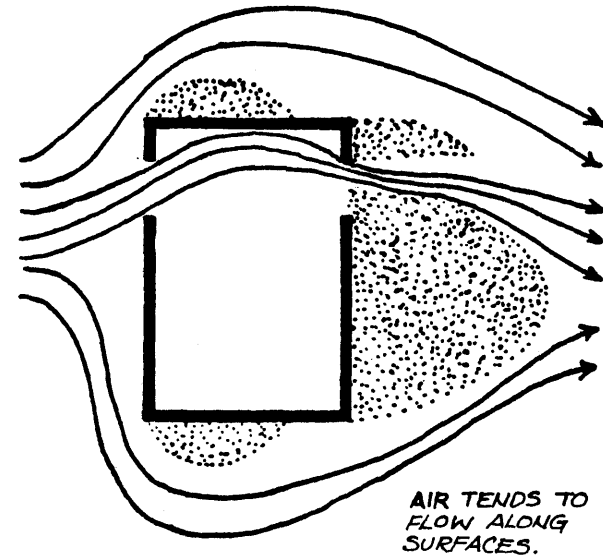
Multiple inlets permit flexibility in the direction of air flow, controlled by the user of the space. Jalousie louvers have a wide range control of wind direction. Air flow through the jalousie is at approximately the same angle at which the louvers are oriented.

4) The quantity of air flow should be controlled by proper sized openings. (Caudill, Some General Considerations in the Natural Ventilation of Buildings, p. 32).

For maximum air change, inlets and outlets should be as large as possible. The greatest flow per unit area of opening occurs with inlets and outlets of equal size. An increase in outlet area causes an increase in air flow, but not in proportion to the added area.

For a variable quantity of air flow, multiple inlet and outlet openings should be provided. This permits adjustment for maximum air change, for no air change, as well as for an intermediate range of controlled quantities of air change.

5) The speed of air flow should be controlled by proper design of inlet and outlet openings.



(Caudill, Some General Considerations in the Natural Ventilation of Buildings, p. 32).

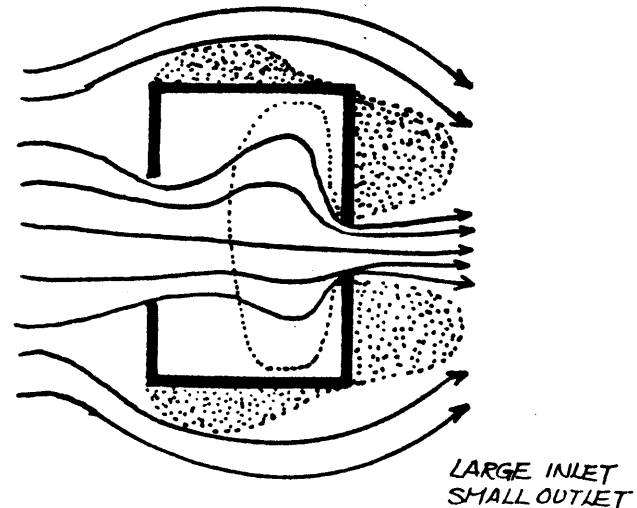
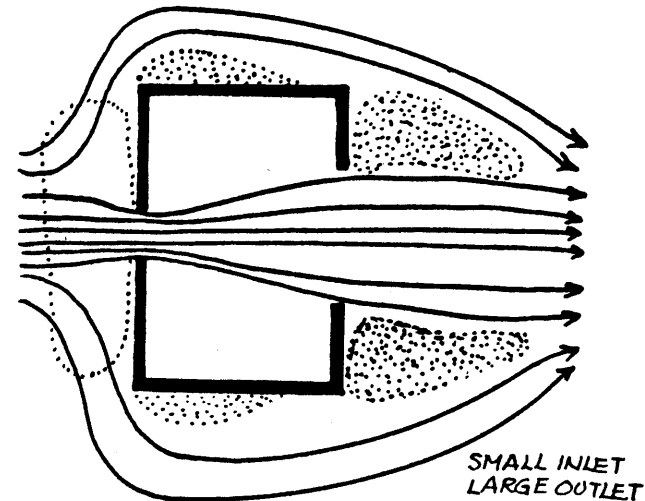
A small inlet in combination with a large outlet results in a relatively high speed of air flow within the building. The flow of air is dammed up by the windward wall and exerts pressure on that wall. The air is forced through the inlet opening at a high rate due to this piling effect. It rushes through the building and out the large opening to an area of negative pressure.

A large inlet in combination with a small outlet causes the reverse to occur. The dam forms inside at the outlet wall, and the increased speed is on the outside of the building.

Multiple inlets and outlets provide flexibility in the speed of an air flow, as well as in the aforementioned direction and quantity of air flow.

6) Interior partitions should facilitate air flow.

Partitions slow the speed of air flow by creating a damming effect and causing abrupt directional changes in air flow. Partitions designed with ventilation louvers at "living" zone height and operable transoms at clerestory height mitigate the decelerating effects of conventional



walls. Partitions should be limited in number and placed with discretion in order to achieve maximum air flow.

7) The building should utilize the "stack effect," especially when there is no wind or its direction is unpredictable.

The stack effect refers to air flow induced by the pressure and temperature differentials that occur between vertically separated points. Warm air is more buoyant than cool air and tends to rise. Greater wind velocities at higher building elevations cause lower pressures at upper portions of the building than at its base. These thermal and pressure forces draw air in through openings low in the building and out through openings high in the building.

When wind and "stack effect" forces act together, resulting air flow is not equal to the sum of the two flows. When the two flows are equal, the actual flow is about 30% greater than that caused by one force.

Limitations to Natural Ventilation in Tall Structures

Prediction of air flow patterns in and around tall structures is difficult. Air sweeps up the windward face of the building, creates vortexes at corners, and forms areas of negative pressure on the leeward side.

The stack effect has an impact on air flow both inside and outside the building. Lower exterior pressure with increasing height causes air to rise through vertical penetrations in tall buildings. This effect is intensified with an inside to outside temperature differential. Warm buoyant air rises in the building pulling cool air in at lower levels.

It is easier to ignore these uncertainties, to seal the building against the outside world, and to use mechanical space conditioning equipment for air supply. In such spirit, installed windows are air tight, rain proof, heat resistant, light resistant, rust resistant, and rot resistant. No concern is shown for air flow through the window; and the structure becomes quite separate from the world outside, an enclosed high-pressure box, a potential glass bomb.

Even with operable windows, most tall struc-

tures are not adequately ventilated. Most multi-story buildings are compact in form, a double-loaded corridor or center core arrangement. Fans pull air out of the corridor to the exterior, creating a negative pressure field. Rooms aligning both the windward and leeward sides of the structure admit outside air. This air is noisily sucked under the doors leading to the corridor to replace that removed.

Such drafty, unpleasant air flow is not proper ventilation. There is no effective use of positive and negative pressure areas. Control of air flow direction, quantity, and speed are disregarded. How air moves around interior obstructions is not addressed. And possibilities of using the stack effect for natural ventilation are ignored.

Design Response to Natural Ventilation

1) Building Location for Wind Access

As a portion of a tall residential structure, the vertical neighborhood is perched above typical obstructions to wind...trees, hills, and buildings. Thus, the wind is assumed to flow to the structure without interference.

2) Use of High and Low Pressure Areas for Air Flow

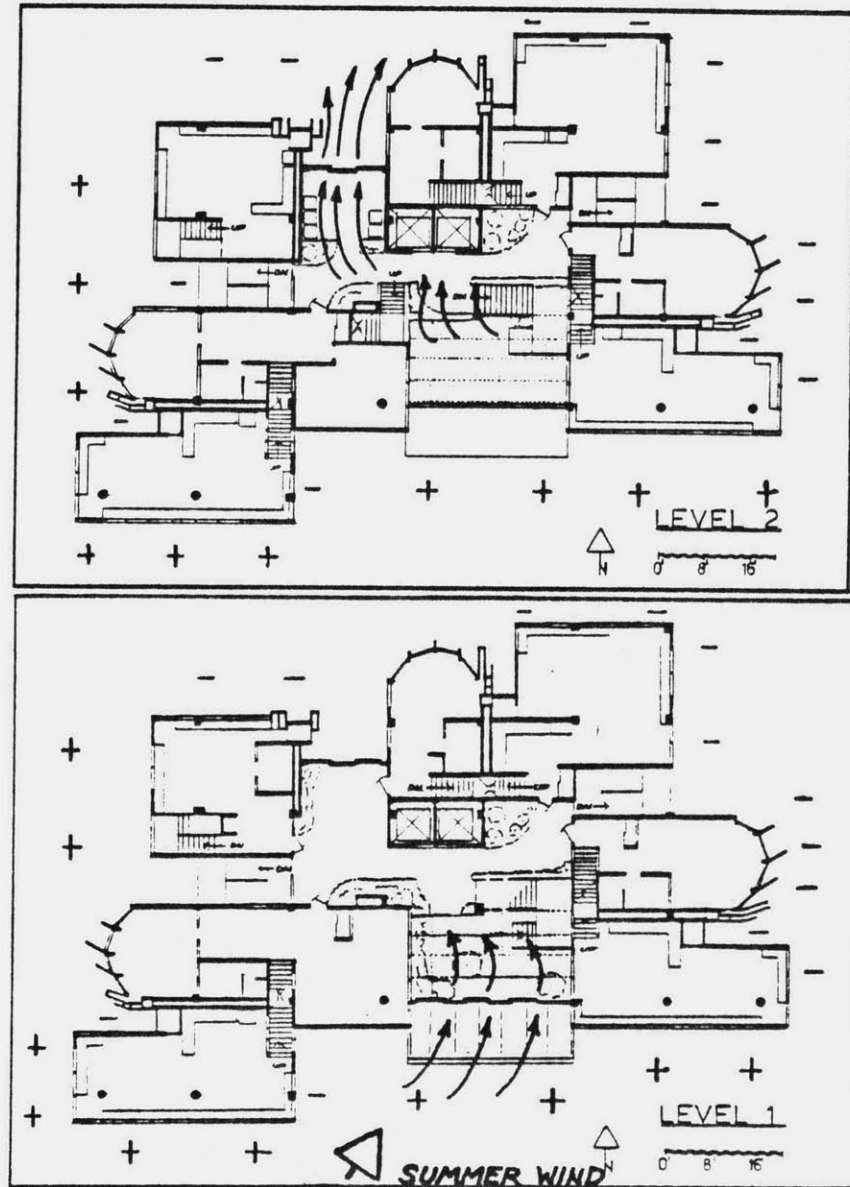
The structure's maximum wall area is facing due south. This orientation is based on criteria for passive solar heating and natural daylighting. The ideal orientation for maximization of wind flow is with the large surface area facing southwest in order to intercept the prevailing summer winds. The south-facing orientation does not cripple natural ventilation, however. When the wind is not from a 90° angle to the building, the air enters the window at the same angle as the outdoor flow, unless diverted by a sash or other obstruction. (Holleman, Air Flow through Conventional Window Openings, p. 13).

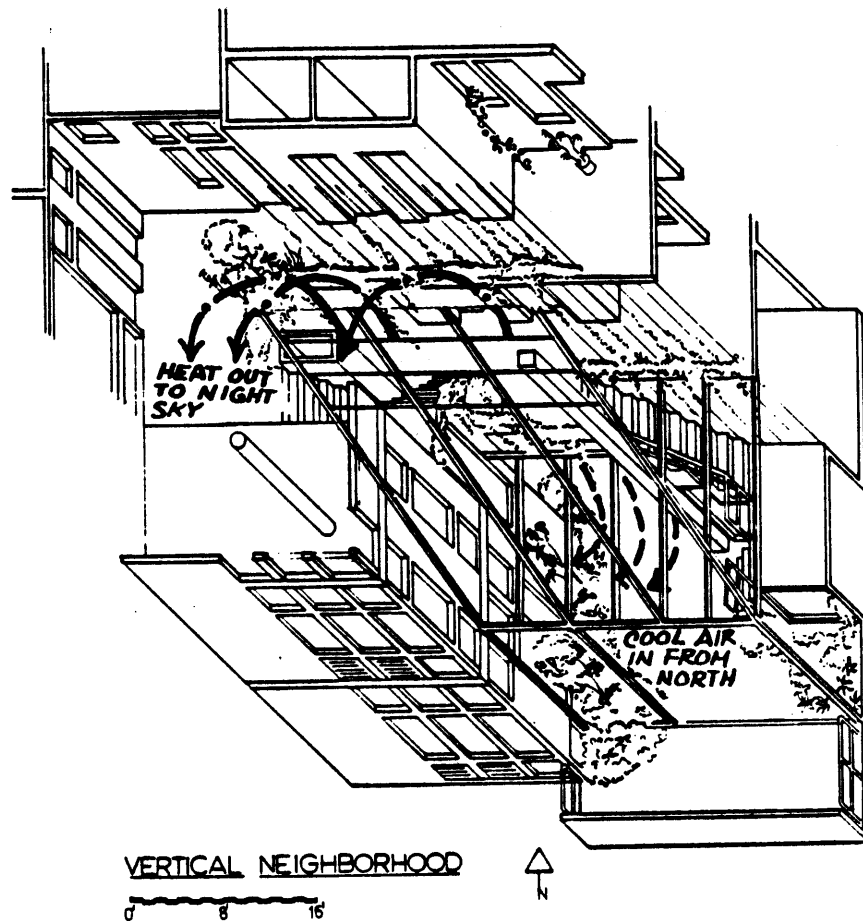
Wind direction is not always from the southwest. It can originate from any direction, and the building is so arranged to take advantage of

a variety of winds. Openings on all sides of the building permit those in positive pressure locations to be inlets and those in wind shadows to be outlets. These two functions are interchangeable for any given opening as the wind direction varies.

During the summer, the neighborhood space usually experiences positive pressure on its south-facing expanse of glass with a wind shadow to the north. Air is drawn in through the open sliders at level 1 and convected back through the space and out the north-facing sliders at the level 2 laundry. This interior breeze is caused mainly by the pressure differential from south to north, and is encouraged by the buoyant, rising warm air from the laundry.

Without wind-induced positive and negative pressure areas, air flow through this three level space still occurs due to thermal forces. On a calm summer night, the vents at the top of the south-facing 3 story "greenhouse" are opened. Hot air which has collected at the top of the glazing during the day escapes to the night sky, inducing cool air in from open sliders to the north. The coolness of the night is stored in the quantities of concrete and potting soil within the public





space. The south-facing awnings are drawn at dawn in order to shade the space from the sun's heat. The stored coolness of the previous night keeps this public space comfortable below exterior summer temperatures throughout the day.

The units exhibit flexibility with multiple openings that serve as either inlets or outlets depending on the wind direction. The many building crenelations create pockets of negative pressure for individual units. This is especially important to the southwest unit, with two weather walls exposed to the prevailing wind. The crenelation at the auxiliary heat exhaust and the void for the fire-stair serve as negative pressure zones for this particular unit.

3) Design and Location of Openings for Air Flow Direction

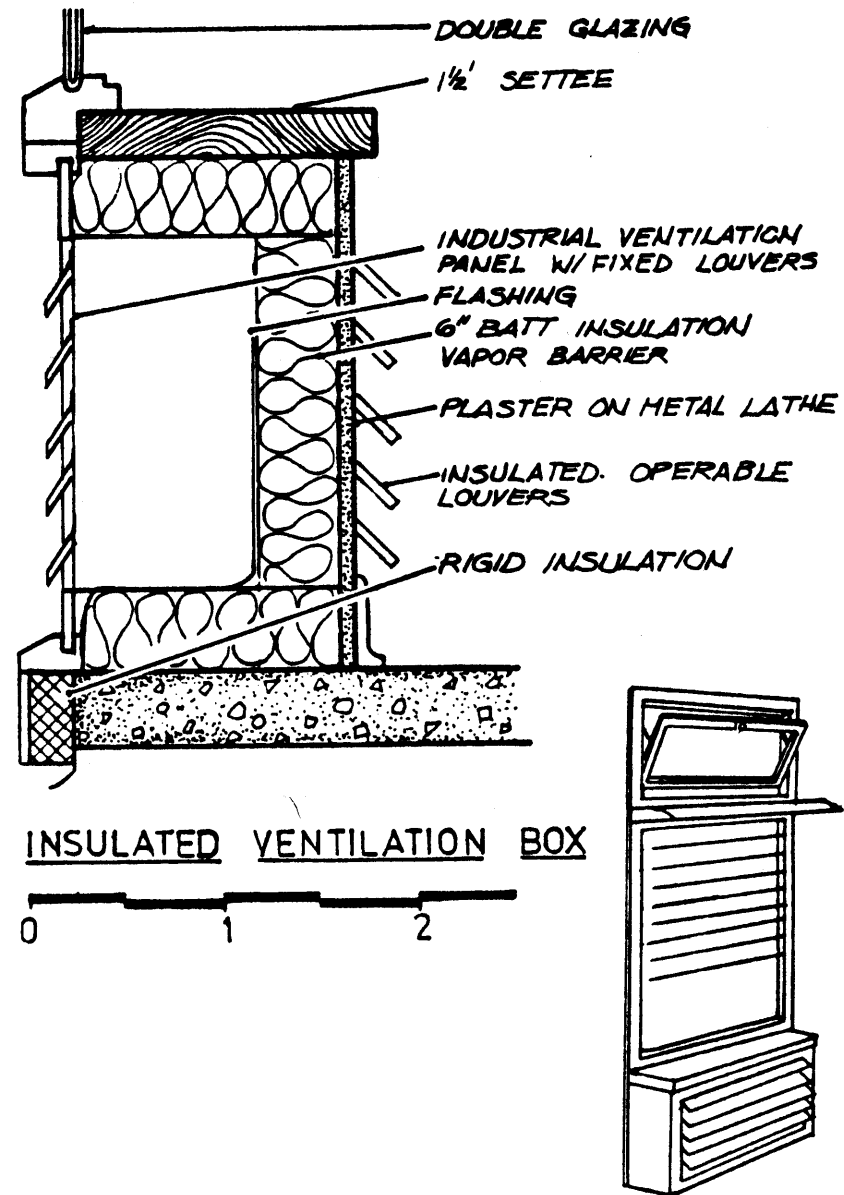
The typical weather wall elevation, as described in previous chapters, is broken horizontally into 3 sections, the clerestory, the nonoperable midheight window, and the opaque weatherproof "ventilation box" below working plane.

The exterior facing of this "ventilation box" is an industrial ventilation panel with fixed louvers to shed wind-driven rains. Behind this

weather shield, the box is composed of 6" expanded polyurethane insulation, a vapor barrier, and plaster on metal lathe with insulated operable louvers in the openings. The box is capped with a 1½' deep settee, serving as a window seat, book shelf, or plant stand. Each box is separated from adjacent ones for control of air flow quantity and direction. The jalousie louvers also permit fine tuning of air flow quantity and direction. They can guide air horizontally, upward, or downward. Their low installation height and capability of directing air downward ensures ample breeze in the "living" zone for summer cooling.

Although winter venting is undesirable in this solar-heated building, the option of natural ventilation in the upper portion of the room is provided. There are times, even in summer, when a direct draft is bothersome. The windows above transom height are operable hoppers, admitting outside air which mixes with the warmer air at ceiling height. These windows open into the room in order to lessen the havoc of unpredictable winds playing on the exterior facade.

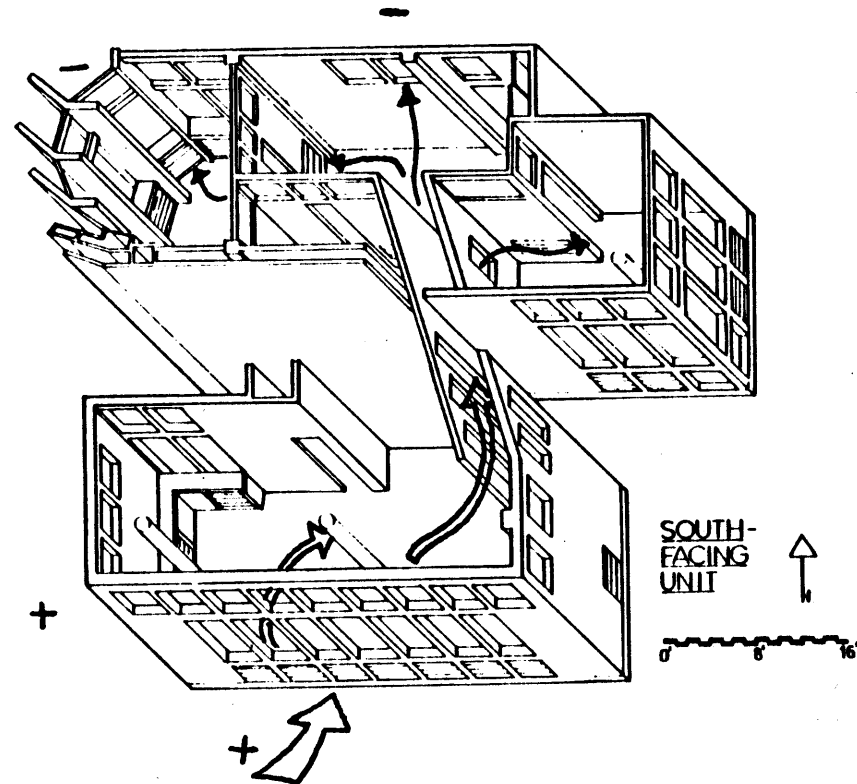
The location of openings in a typical south-facing unit permit a natural air flow pattern from



south to north. This unit is organized with its area of solar collection and high internal heat gains one level below the bedroom space. The bedroom space is set back from the sun-accessible south facade and relies on the convection of heat from the lower zone up the stair shaft.

Natural ventilation works in a similar manner. The high pressure walls are usually those to the south and west. With opened louvers in the lower space facing high-pressure areas, fresh air enters the apartment. It is convected up the stair shaft to the bedroom zone, where it is emitted through north-facing outlets at the fire stair, an area of low pressure. The overall air flow pattern is naturally from southwest to north. This pattern is duplicated within the southeast unit, where air flows from the lower south-facing rooms to the upper north-facing rooms. This is tested in the wind tunnel and reported in detail in Appendix E.

The northwest unit, as a stacked duplex, vents its floors separately from west to north. Assuming a southwest wind, the northeast unit must depend on the stack effect for natural ventilation; for it is in the wind shadow of the entire building.



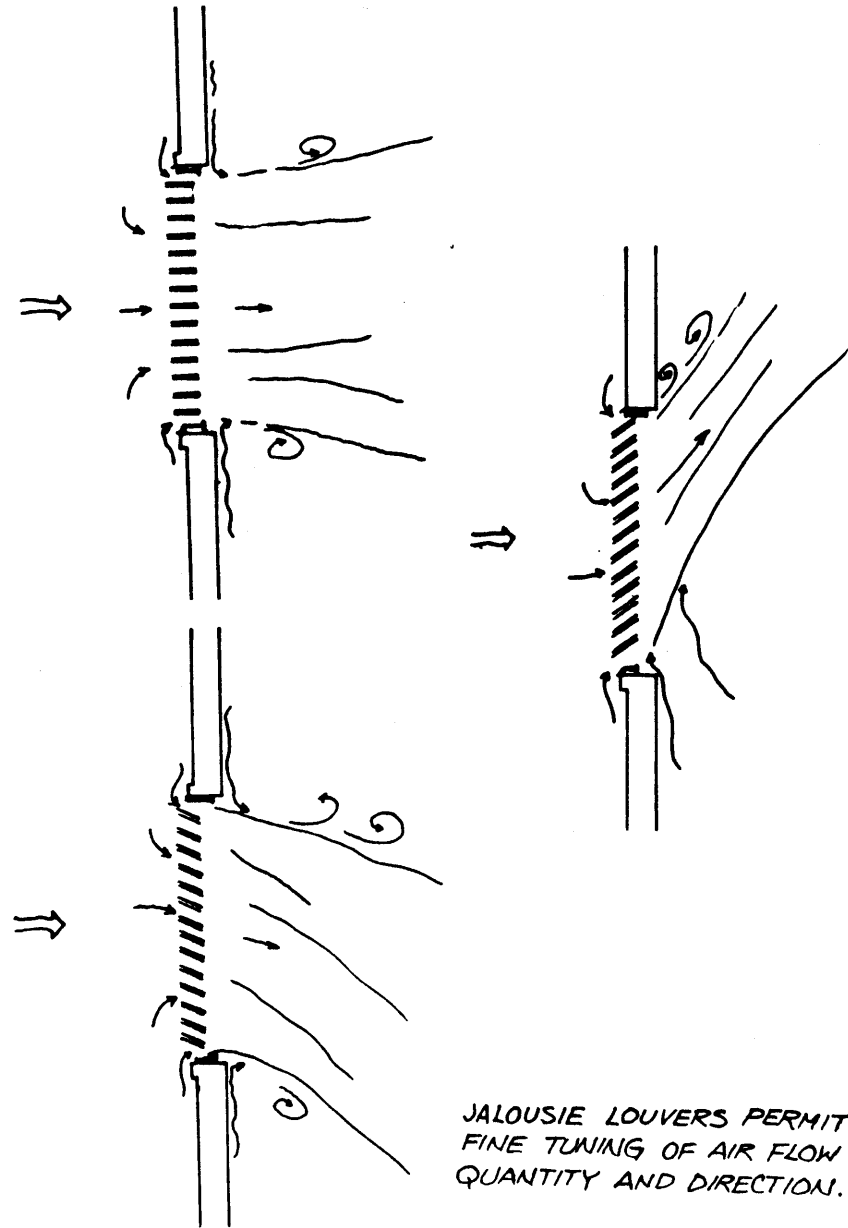
4) Size of Openings for Air Flow Quantity

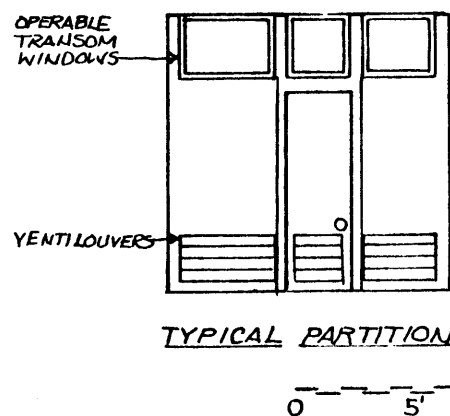
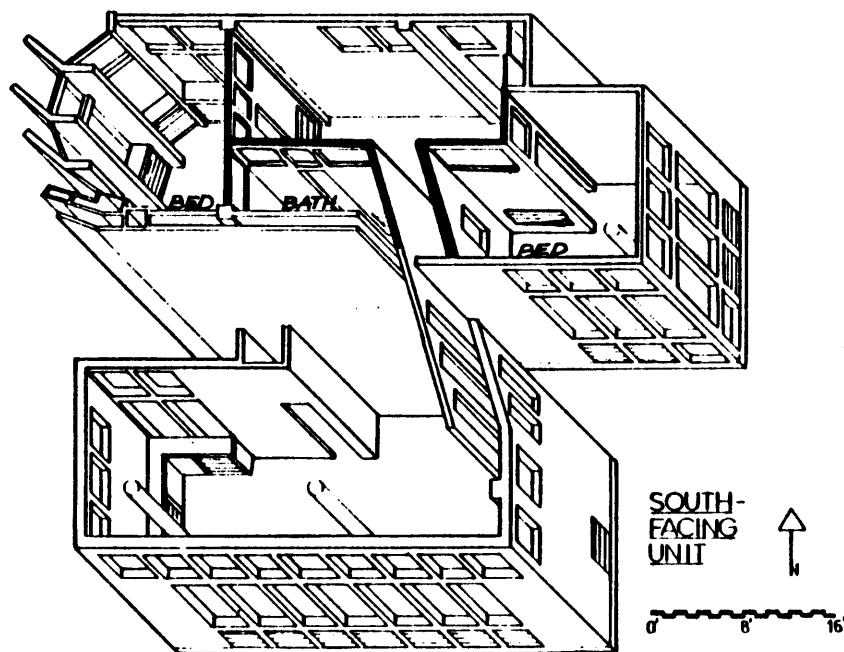
The proper size opening for control of air flow quantity is not certain in a tall structure. Wind speeds may be 3 times that of ground wind and wind direction unpredictable. On a hot summer day, a very open, breezy apartment may be preferred, while a limited amount of fresh air is needed on a cool autumn day. The air flow quantity is the choice of the dweller, who also controls the direction and vertical level of air currents.

A typical south-facing unit has from 15 to 24 individual jalousie ventilation units below the settee at the weather wall. Each of these insulated weather-proof boxes is individually controlled, permitting any number of the units to be opened to airflow. The louvers add to this flexibility. They can be opened wide for full air flow or just barely cracked, permitting a slight infiltration. A comparable number of hopper clerestories permits similar flexibility for overhead ventilation.

5) Design of Openings for Air Flow Speed

The quantity of inlets and outlets allows control of air flow speed; for the ratio of inlet area to outlet area affects velocity. Opening





more outlets than inlets increases the rate of air flow through the space due to the damming effect and the resulting high pressure on the windward wall. Opening more inlets than outlets slows the interior breeze; for the damming effect occurs on the inside of the leeward wall.

6) Interior partitions which facilitate Air Flow

Air has inertia and will travel in a straight line until an obstacle causes a change in direction. This slows the air flow.

Interior partitions are kept to a minimum in each unit in order to facilitate both air flow and the aforementioned distribution of light and heat. The only partitions within a unit are those required for privacy, partitions defining the bedrooms and bath. These partitions are equipped with ventil-louvers below working plane. This allows air to flow within the "living" zone. The transoms are operable for overhead air flow.

With louvers below and an operable transom above, the vertical plane of moving air can change from room to room. With settee louvers open in the kitchen-dining-living space, air movement occurs within the "living" zone. The air travels up the

stair shaft. With only transoms open to the bedrooms, the air flow is directed to the ceiling, avoiding direct drafts near the floor. Individual preference clearly reigns, unit by unit and room by room.

7) Use of the Stack Effect

The stack effect will have an impact on air flow within the building. The entire building could function as one gigantic stack depending on the height of the building, the extent of vertical penetration, and the difference in indoor and outdoor temperatures (Service Systems, p. 17).

A large-scale stack effect is prevented in the design of a vertical neighborhood.

The height of the building, 240', is comparable to that of Peabody Terrace, 3 residential towers situated on the wind-swept banks of the Charles River. Natural ventilation and the use of balconies indicates tolerable wind behavior at these heights. It also demonstrates that tall structures need not be totally enclosed and pressurized to counteract the stack effect.

The design for a vertical neighborhood is vertically zoned into 6 neighborhoods of 4 stories.

Each neighborhood is independent of the others, thus reducing the effective height of the building from 24 stories to a stacked series of 6 buildings, 4 stories each. Such an arrangement prevents air from entering at the lowest level, where the pressure is highest, and rushing to the top of the structure where the pressure is lowest. This would prohibit the entry of air at midheight openings.

This building is independent of mechanical space conditioning systems. Vertical penetration is limited to the elevator shaft, pressurized if needed. This, too, works against a large-scale stack effect.

When properly controlled, the stack effect can be a bonus to the natural ventilation of a tall structure. Air flow within a building need not depend solely on wind pressures. Air can be coaxed to move up a chimney stack via the pressure and temperature differentials between the inlet base and outlet cap of the stack.

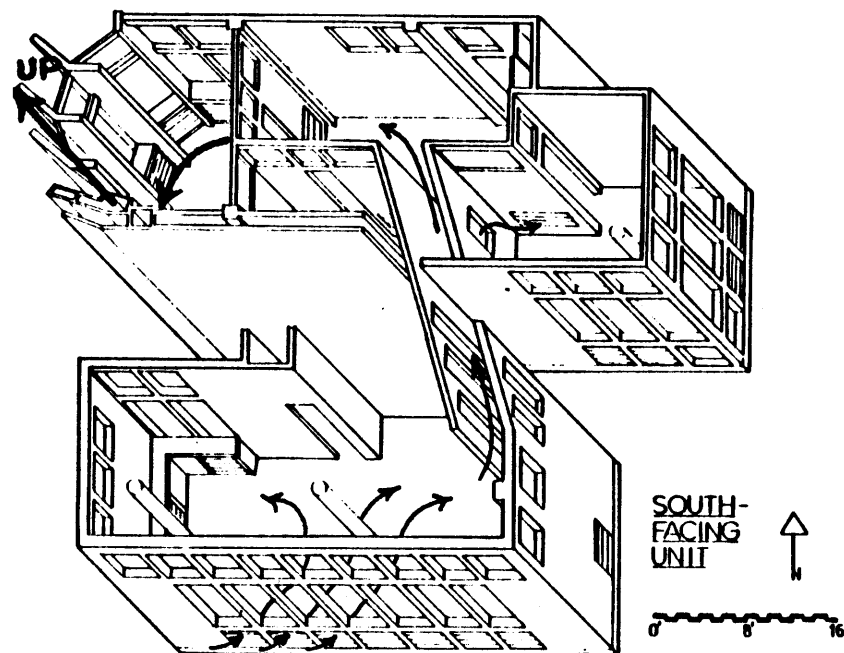
To use the stack effect in a multistory structure is logical. The needed height exists, and the stack ensures natural ventilation when the wind is not cooperative.

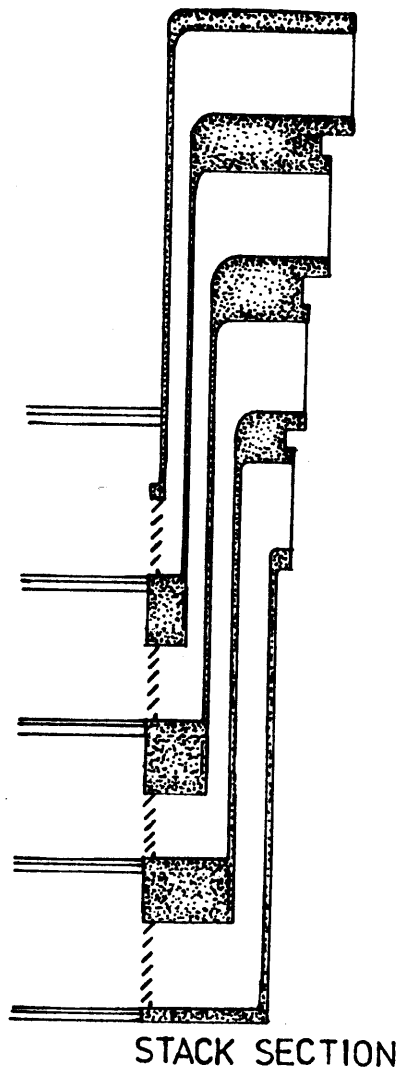
Each unit in the vertical neighborhood has a vertical stack associated with the auxiliary heat exhaust. These stacks, which separate the round elements from the rectangular in plan, also couple as shading fins on the east- and west-facing building facades. They demarcate each neighborhood, as the flues of individual units are gathered into one giant stack per neighborhood. The separate flues for each unit are maintained to avoid short-circuiting problems. Each unit's outlet occurs 4 levels above its inlet, a dramatic termination which creates offsets in the overall stack.

The stack inlet, for a typical south-facing unit occurs at the weather wall of the second level. With windows opened on the lower level, the entire unit benefits from natural ventilation. The air flows through the lower level, up the stair shaft, and through the upper level to the stack. The stack is equipped with insulated louvers, similar to those on the "ventilation boxes." Unwanted air currents are thereby avoided by tightly sealing the louvers.

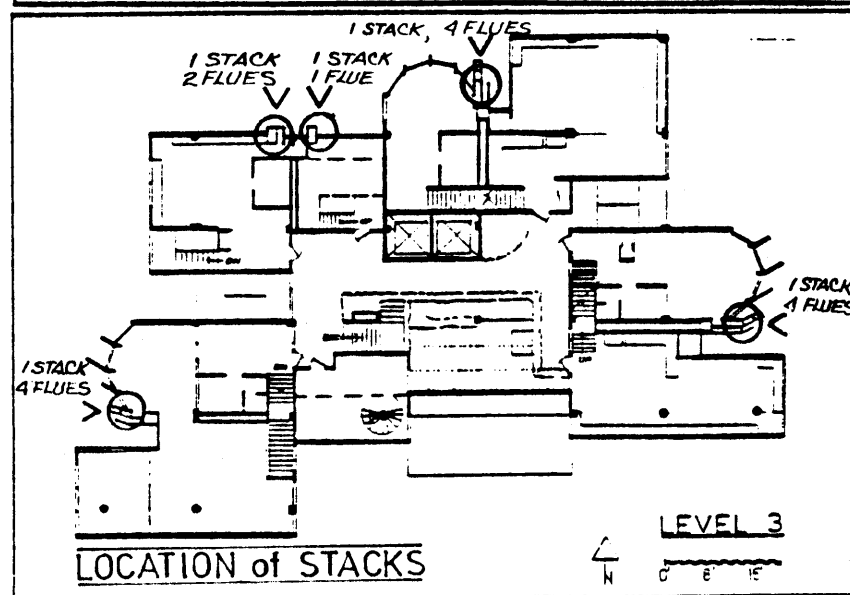
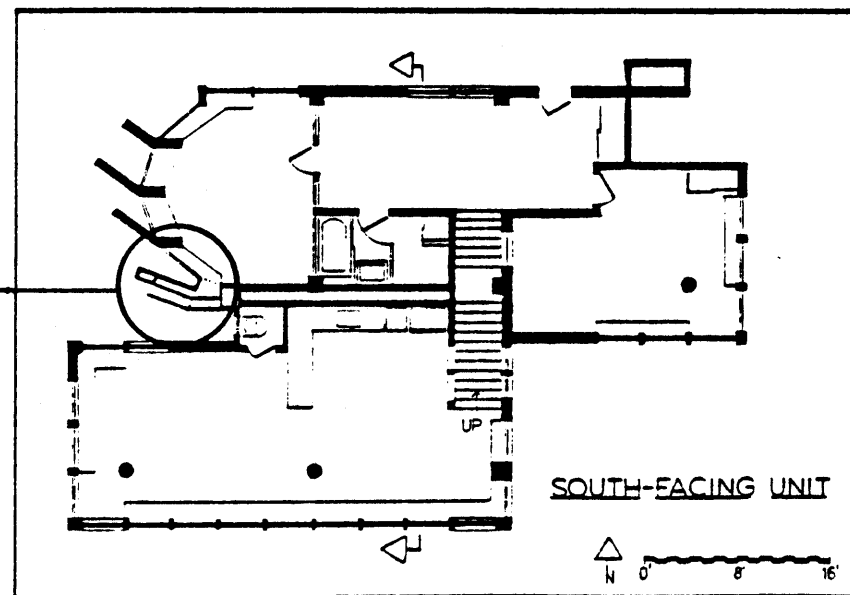
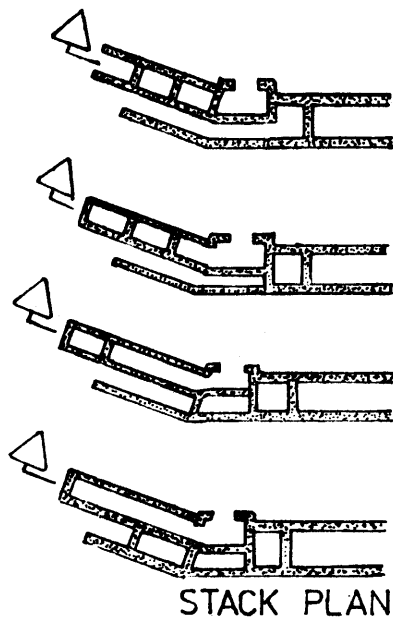
The stack is sized for a typical south-facing unit, as reported in Appendix F. Air flow is established to remove hourly internal heat gains,

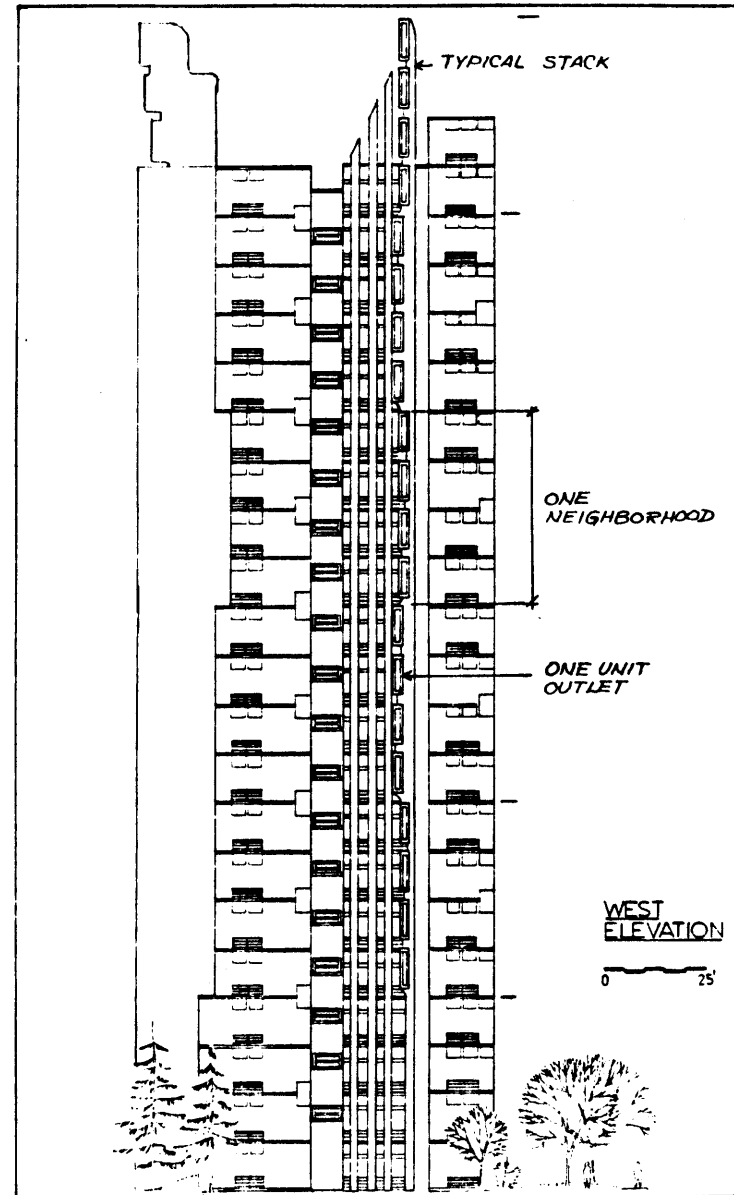
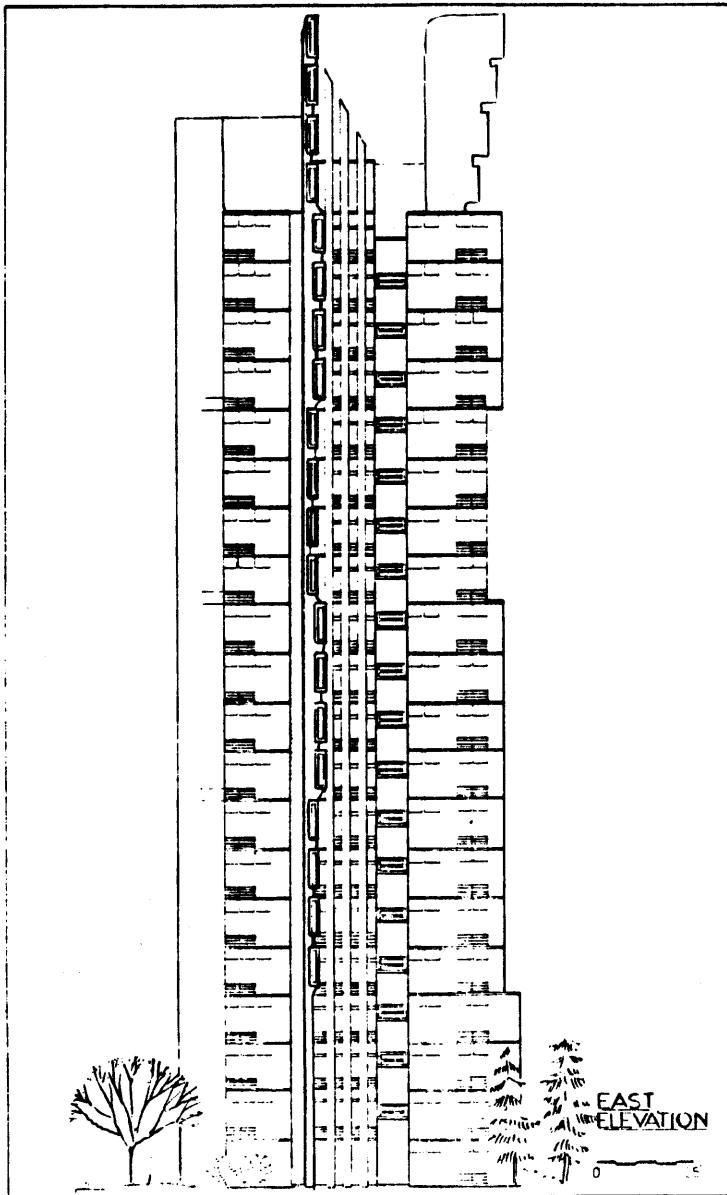
2,257 BTU/HOUR. With interior temperatures exceeding exterior temperatures by 5° , an inlet and outlet opening of 3 square feet is needed. This area is doubled in the actual design. The stack is able to remove hourly internal heat gains with an indoor-outdoor temperature difference of only 1.3°F .





DOUBLE STACK:
STACKS ALTERNATE
WITH EACH NEIGHBORHOOD





CHAPTER 5 AUXILIARY HEATING

Auxiliary Heating System

A solar-tempered building gains much of its required heat energy from the sun. The building's peak demand, however, does not correspond in time to the sun's maximum heat output.

The building's greatest daily heating load occurs during the night, in the absence of the sun. Its annual heating load is concentrated during the cold winter months when the sun contributes its minimum seasonal offering. And with ample amounts of solar energy available during the summer months, the building requires no auxiliary heat.

Because the need for thermal energy and its availability are out of phase, a back-up heating system is required.

A single prolonged period of very cold, cloudy weather may be enough to warrant a full-size conventional back-up heating system. Passive solar structures may even require over-sized auxiliary heating systems. Large areas of south-facing glass, effective for solar collection, also add to the nighttime building load. As such, walls with large expanses of glazing for solar collection contribute more to conduction heat loss than conventional walls with limited amounts of glazing. These

spaces suffer severe consequences during sustained periods of cold, sunless weather; and solar assist heating must be designed for such peak demands.

A heating system is composed of four basic elements: 1) a combustion chamber in which to burn fuel, producing heat; 2) a fluid (water, steam, or air) for conveying the heat; 3) conduits in which to transport the fluid from the combustion chamber to the load; 4) a terminal unit for distributing heat at the load.

Each living unit is provided with its own back-up system, an individually fired gas hydronic packaged heater.

1) The individual gas-fired boiler has a 43,800 BTUH capacity, more than enough to supply each unit's peak load and domestic hot water needs. It has no storage tank; the only heat storage is the volume of boiler water surrounding the heater coil. A hot water tank for domestic supplies is connected to this heater via a water to water heat exchanger.

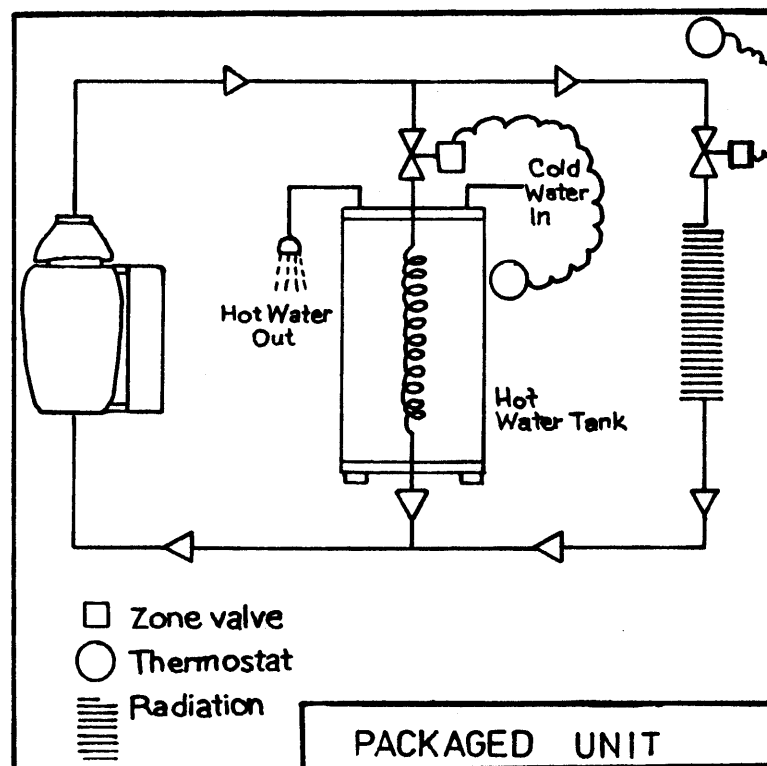
2) Hot water, as the heat-conveying medium, relinquishes its sensible heat before returning to the boiler for reheating.

3) Type K copper pipe is used to transport the hot water from the heater to the terminal unit. With unit by unit heating, there are no long runs of piping. The necessary circulation is maintained by the difference in density between the hot water and the cool water returning to the heater.

4) The thermostat and terminal unit for heat emission are located at the base of the stair shaft on the lower level, an area of solar collection and high internal heat gains. This conserves the use of auxiliary heat. It also utilizes the same convective currents which carry the passive heat of solar collection and internal heat gains up the stair shaft for even distribution throughout the upper level.

Each square foot of radiator surface has an hourly heat emission of 150 BTUH. With a reasonable load of about 3,500 BTUH, a surface area of 23 square feet is required. One 2½' x 5' x 6" radiator has more than enough surface area of piping for this output. Multiple radiators may be needed for peak loads.

Why is this back-up system chosen over a conventional centralized heating system for the entire structure?



The individual units are in keeping with the concept of environmentally self-sufficient units arranged around a communal space, the indoor/outdoor vertical neighborhood. Each unit functions as its own solar collector, solar storehouse, and heat trap. Each unit is naturally daylighted and ventilated, independent of the rest of the structure. This permits flexibility and grants inhabitants control over their environmental comfort. Individual back-up heating systems allow this same freedom.

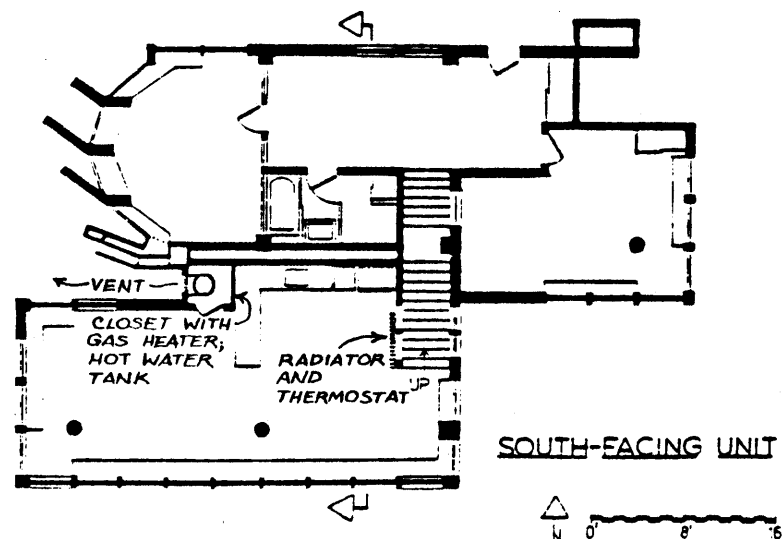
The system's space-saving dimensions, 38" x 19" x 14" permit installation in a closet on the lower level of each unit. The domestic hot water heater is housed in the same closet.

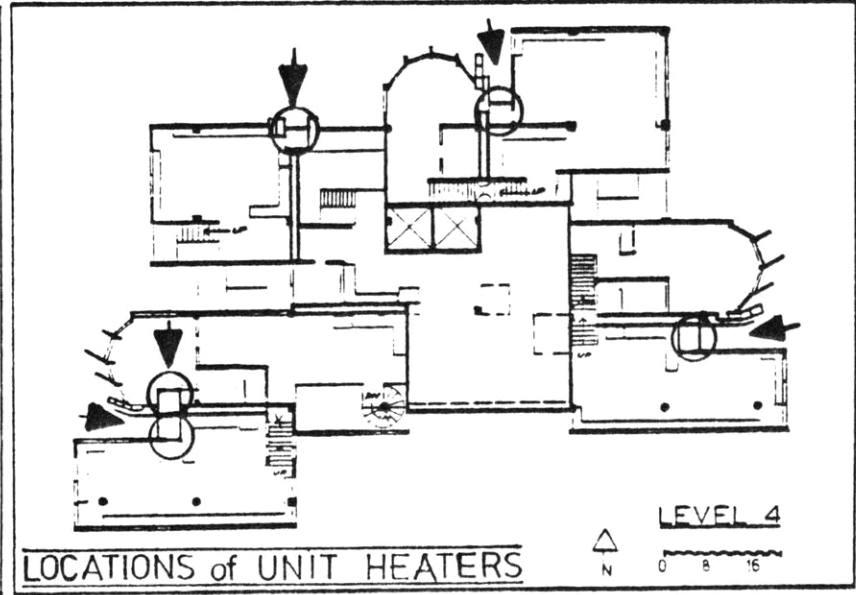
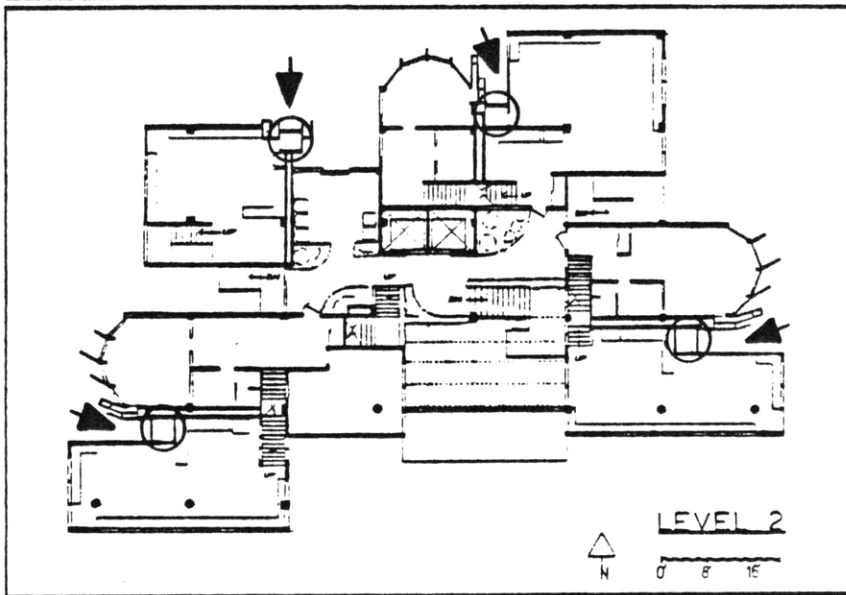
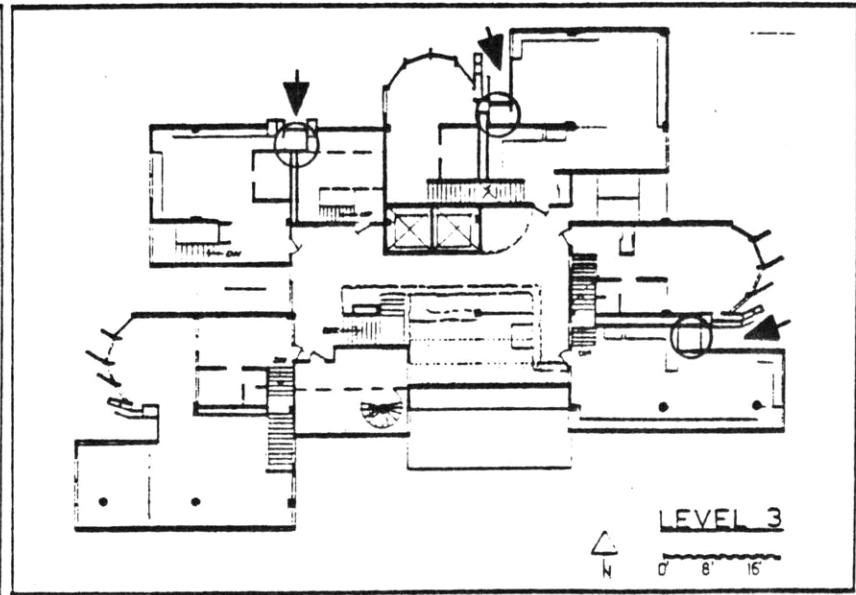
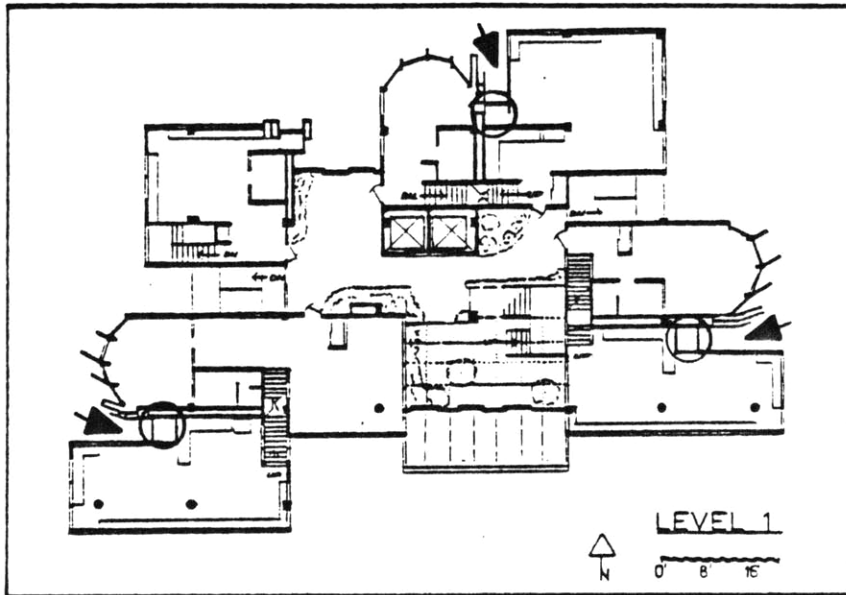
The light-weight boiler is hung on a weather wall with its exhaust outlet feeding directly into an exterior negative pressure zone. The vented gases are thus pulled out and away from the building. Such simple venting saves chimney costs, conserves space, and helps to limit the number of vertical penetrations which contribute to building stack effect.

All piping from the heat generator to the terminal unit is within the space defined as load. Thus, the distribution heat loss is zero. With a

centralized heating system, however, the heat conveying fluid continually loses heat through lengths of piping which extend from the boiler to the distant load.

The initial cost of supplying each apartment with its own packaged auxiliary heating unit is 30% less than the cost of providing one large centralized heating system for the entire building. The estimates, outlined in Appendix G, indicate the largest savings accrue in the method of venting individual heaters directly to the outside as opposed to venting through large chimney stacks, as required for a central boiler.





APPENDICES

APPENDIX A-1

DIRECT GAIN CALCULATIONS

TYPICAL SOUTH-FACING UNIT

(LOWER LEVEL) Philip W. B. Niles
"A Simple Direct

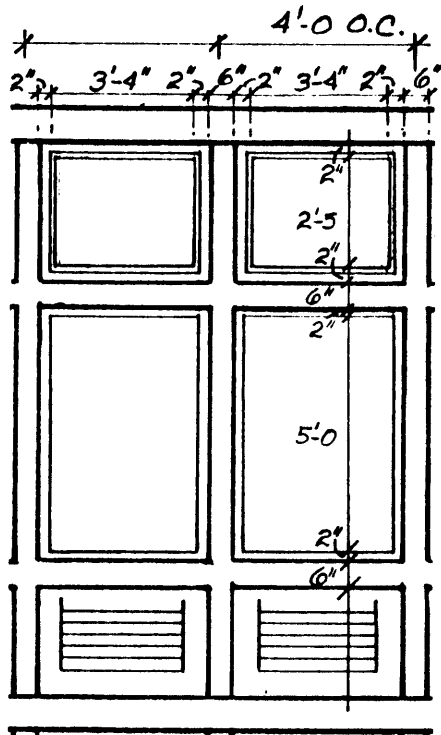
Gain Passive House
Performance Prediction Model"

Passive Solar
State of the Art Proceedings of the 2nd National
Passive Solar Conference

1/4" EXPOSED AGGREGATE
GLASS REINFORCED
PANEL R = 0.32

6" EXPANDED POLYURETHANE
6 x 5.88 R = 35.3

PLASTER ON METAL
LATH R = 0.1
R_T = 35.7



CASEMENT
DOUBLE GLAZING
8 SQ.
FT.

NONOPERABLE
DOUBLE GLAZING
16.67 SQ.
FT.

APPENDIX A-1

$$\text{① AVERAGE INCOMING INSOLATION} = \frac{\text{SOLAR HEAT GAIN FACTOR} \times \text{TRANSMISSION CORRECTION FACTOR}}{24 \text{ HOURS}}$$

$$Q_s = \frac{1388 \text{ BTU/DAY} \times (.88)^2 \times .80 \text{ URBAN POLLUTION}}{24 \text{ HOURS/DAY}}$$

$$Q_s = 360 \text{ BTU/HR SQ. FT.}$$

$$\text{② WALL: } U = 1/R_T \quad U_{\text{WALL}} = 0.028$$

$$A_{\text{WALL}} = \text{SOUTH} + \text{EAST} + \text{NORTH} + \text{WEST} \\ 224 + 121 + 107 + 115$$

$$A_{\text{WALL}} = \sim 568 \text{ SQ. FT.}$$

$$\text{WINDOW: } U = 0.55 \text{ DOUBLE GLAZING}$$

$$A_{\text{WINDOW}} = \text{SOUTH} + \text{EAST} + \text{NORTH} + \text{WEST}$$

$$188.7 + 22.6 + 32.67 + 24$$

$$A_{\text{WINDOW}} = 268 \text{ SQ. FT.}$$

$$\text{INFILTRATION: } \frac{1}{2} \text{ AIR CHANGE PER HOUR} \times 7,128 \text{ CUBIC FEET} \times .018 \\ 64.15$$

$$U_{\text{A TOTAL}} = U_{\text{A WALL}} + U_{\text{A WINDOW}} + \text{INFILTRATION}$$

$$U_{\text{A TOTAL}} = (0.028)(568) + (0.55)(268) + 64.15$$

$$U_{\text{A TOTAL}} = 227 \text{ BTU/HOUR } ^\circ\text{F}$$

DIRECT GAIN INTERIOR TEMPERATURE
TEMPERATURE SWINGS

APPENDIX A-1

$$\textcircled{3} \text{ INTERIOR EQUILIBRIUM TEMPERATURE} = \frac{\text{GLASS AREA (SOUTH-FACING)} \times \text{AVERAGE INCOMING INSOLATION}}{UA_{\text{TOTAL}}} + T_{\text{OUT}}$$

$$T_e = \frac{188.67 \text{ SQ FT} \times 36 \frac{\text{BTU}}{\text{HR SQ FT}}}{227 \frac{\text{BTU}}{\text{HOUR °F}}} + 38^\circ$$

$$T_e = 68^\circ \text{ F}$$

$$A_g = 188.7 \text{ SQ FT.}$$

$$q_{\text{CASEMENT}} @ 8 \text{ SQ FT}$$

$$7 \text{ NONOPERABLE @ } 16.67 \text{ SQ FT}$$

$$\textcircled{4} \text{ OUTDOOR TEMPERATURE AMPLITUDE} = \frac{T_{\text{MAX}} - T_{\text{MIN}}}{2}$$

$$A_{\text{OUT}} = \pm 7.5^\circ \text{ F}$$

$$\textcircled{5} \text{ ZERO MASS AMPLITUDE} \quad T_e - T_{\text{OUT}} = 30^\circ$$

$$68 - 38$$

$$A_{\text{OUT}} = 7.5^\circ$$

$$A_z = \pm 50^\circ$$

$$\textcircled{6} h = 1 \text{ FOR DISTRIBUTED CONCRETE STORAGE}$$

$$MC_s, \text{ EFFECTIVE HEAT CAPACITY (BTU/FT}^2 \text{ °F)}$$

$$\text{ASSUME 4" CONCRETE}$$

$$MC_s = 9.47$$

$$\textcircled{7} \text{ TEMPERATURE SWINGS CONVECTIVE CASE}$$

$$T_{\text{OUT}} = 38^\circ$$

$$T_e = 68^\circ$$

$$Q_s = 36 \text{ BTU/HR/SQ FT.}$$

$$A_{\text{ST}} = \text{CEILING} + \text{BACK WALL}$$

$$A_{\text{ST}} = 868 \text{ SQ FT. CONCRETE}$$

$$a = \frac{A_{\text{ST}}}{A_g}$$

$$a = \frac{868}{188.7} = 4.6$$

$$\frac{(T_e - T_{\text{OUT}})ah}{Q_s} = \frac{(68 - 38) 4.6 (1)}{36} = 3.8$$

$$MC_{\text{STO}}/h = 9.47$$

$$\frac{A_c}{A_z} = 0.23 \quad 0.23(50)$$

$$A_c = \pm 11.5^\circ \text{ F}$$

$$\textcircled{8} \text{ TEMPERATURE SWINGS RADIATIVE CASE}$$

$$\frac{T_e - T_{\text{OUT}}}{A_{\text{OUT}}} = \frac{68 - 38}{7.5} = 4$$

$$MC_{\text{STO}}/h = 9.47$$

$$A_r/A_c = 0.47$$

$$0.47(11.5) = \pm 5.4^\circ \text{ F}$$

$$A_r = \pm 5.4^\circ \text{ F}$$

DIRECT GAIN

INTERIOR TEMPERATURE
TEMPERATURE SWINGS

TYPICAL SOUTH-FACING UNIT

(UPPER LEVEL... DOES NOT OCCUR
ON SOUTHEAST UNIT)

APPENDIX A-1

① $Q_s = 36 \text{ BTU/HR/SQ FT.}$

② WALL: $U = 0.028$ EAST-FACING WALL
INTERIOR TO "GREENHOUSE"
 $A_{\text{WALL}} = 146 \text{ SQ FT}$

WINDOW: $U = 0.55$
 $A_{\text{GLASS}} = 74 \text{ SQ FT}$

INFILTRATION: $\frac{1}{2} \text{ AIR CHANGE/HOUR} \times 3,080 \text{ CUBIC FEET} \times .018$
 27.72

$UA_{\text{TOTAL}} = UA_{\text{WALL}} + UA_{\text{WINDOW}} + \text{INFILTRATION}$

$UA_{\text{TOTAL}} = (0.028)(146) + (0.55)(74) + 27.72 + \frac{1}{2} \text{ EAST WALL WINDOW}$
 $UA_{\text{TOTAL}} = \sim 90 \text{ BTU/HOUR OF } (20.3 + 2.24)$

③ $T_e = \frac{74 \text{ SQ FT} \times 36 \text{ BTU/HOUR SQ FT}}{90} + 38$

$T_e = 68^\circ \text{ F}$

$A_g = 74 \text{ SQ FT}$

3 CASEMENT @ 8 SQ FT
3 NONOPERABLE @ 16.67 SQ FT

④ $A_{\text{OUT}} = \pm 7.5^\circ \text{ F}$

⑤ $A_z = \pm 50^\circ \text{ F}$

⑥ $h = 1$
 $MC_s = 9.47$

⑦ $A_{\text{ST}} = \text{CEILING} + \text{BACK WALL}$

$A_{\text{ST}} = 320 \text{ SQ FT. CONCRETE}$

$Q = \frac{320}{74} = 4.3$

$\frac{(T_e - T_{\text{out}}) ah}{Q_s} = \frac{(68 - 38) 43 (1)}{Q_s} = 3.6$

$MC_{\text{sto}/h} = 9.47$

$\frac{A_c}{A_z} = 0.26$

$A_c = \pm 13^\circ \text{ F}$

⑧ $\frac{T_e - T_{\text{out}}}{A_{\text{out}}} = \frac{68 - 38}{7.5} = 4$

$MC_{\text{sto}/h} = 9.47$

$A_r/A_c = 0.47$

$0.47(13) = \pm 6^\circ \text{ F}$

$A_r = \pm 6^\circ \text{ F}$

DIRECT GAIN INTERIOR TEMPERATURE
TEMPERATURE SWINGS

PUBLIC SPACE

① $Q_s = 36 \text{ BTU/HR/SQ FT.}$

② WALL: $U = 0.028$

$A_{\text{WALL}} = \sim 0$

WINDOW: $U = 0.55$ SOUTH-FACING DOUBLE GLAZING

$U = 0.26$ NORTH, EAST, AND WEST-FACING HEAT MIRROR

$A_{\text{SOUTH}} = 864 \text{ SQ FT.}$

$A_{\text{NORTH EAST WEST}} = 191 \text{ SQ FT.}$

INFILTRATION: $\frac{1}{2} \text{ AIR CHANGE PER HOUR} \times 45,222 \text{ CUBIC FEET} \times 0.018$
407

$U A_{\text{TOTAL}} = U A_{\text{WALL}} + U A_{\text{SOUTH}} + U A_{\text{NORTH EAST WEST}} + \text{INFILTRATION}$

$U A_{\text{TOTAL}} = 0 + .55(864) + .26[327 + 271 + 136] + 407$

$U A_{\text{TOTAL}} = 1,073 \text{ BTU/HR OF}$

③ $T_e = \frac{864 \times 36 \text{ BTU/HR OF}}{1073} + 38^\circ$

$T_e = 67^\circ \text{F}$

$A_g = 864 \text{ SQ FT.}$

④ $A_{\text{OUT}} = \pm 7.5^\circ \text{F}$

⑤ $A_z = 49^\circ \text{F}$

⑥ $h = 1$
 $MC_{\text{STO}} = 9.47$

APPENDIX A-1

⑦ $A_{\text{ST}} = \text{AREA of FLOOR} + \text{CEILING of LEVEL 1} + \text{CEILING of LEVEL 2} + \text{CEILING of LEVEL 3} +$

$(\text{SOUTH-FACING ELEVATOR WALL - DOORS}) + \text{STAIRS DOWN TO LEVEL 1 UNDERSIDE, ONLY} +$

$\text{STAIRS UP} + \text{WALL @ NORTH EAST UNIT} +$

$\text{WALL @ SOUTH EAST UNIT} + \text{WALL @ SOUTH WEST UNIT}$

$A_{\text{ST}} = 4,714 \text{ SQ FT.}$

$a = \frac{A_{\text{ST}}}{A_g}$

$a = \frac{4714}{864}$

$a = 5.5$

$\frac{T_e - T_{\text{OUT}}}{Q_s} \frac{ah}{Q_s} = \frac{68 - 38(5.5)}{36} = 4.4$

$MC_{\text{STO}}/h = 9.47$

$A_c/A_z = 0.2 \quad A_z = 49$

$A_c = \pm 9.8^\circ$

⑧ $\frac{T_e - T_{\text{OUT}}}{A_{\text{OUT}}} = \frac{68 - 38}{15} = 4$

$MC_{\text{STO}}/h = 9.47$

$A_r/A_c = 0.47$

$A_r = 9.8(0.47) = \pm 4.6^\circ$

$A_r = \pm 4.6^\circ \text{F}$

DIRECT GAIN INTERIOR TEMPERATURE TEMPERATURE SWINGS

APPENDIX A-2

IN ORDER TO CALCULATE THE FRACTION OF THE MODIFIED UNIT LOAD THAT IS FURNISHED BY THE SUN, THE AMOUNT OF SOLAR RADIATION TRANSMITTED THROUGH THE UNIT'S GLAZING IS NEEDED. BEAM AND DIFFUSE RADIATION COMPOSE THE GAIN THROUGH EAST AND WEST-FACING WINDOWS. ONLY DIFFUSE RADIATION ENTERS THE NORTH-FACING WINDOWS, EXCEPT IN SUMMER DURING THE VERY EARLY MORNING OR THE VERY LATE AFTERNOON.

AVERAGE DAILY INSOLATION FOR A SURFACE OF ANY ORIENTATION IS DETERMINED BY A T159 PROGRAM. VALUES OF THE BEAM, DIFFUSE, AND REFLECTED COMPONENTS ARE GIVEN FOR EAST AND WEST ORIENTATIONS. A GROUND

REFLECTANCE OF 0.2 AND AN ATMOSPHERIC CLEARNESS OF 0.85 IS ASSUMED. THE DATA IS AVERAGE DAY INCIDENT RADIATION, GIVEN FOR THE 21ST DAY OF EACH MONTH.

BECAUSE THE AMOUNT OF ENERGY ACTUALLY ENTERING A SPACE DEPENDS ON THE TRANSMISSION OF THE GLAZING MATERIAL AT A PARTICULAR ANGLE OF INCIDENCE, THE DATA FROM THE FIRST PROGRAM MUST BE REFINED. ANOTHER T159 PROGRAM CALCULATES BEAM, DIFFUSE, AND TOTAL RADIATION BOTH INCIDENT UPON AND TRANSMITTED THROUGH A SPECIFIC GLAZING MATERIAL. AVERAGE TRANSMISSION FACTORS FOR VARYING ANGLES OF INCIDENCE ARE GRAPHICALLY ESTIMATED. AGAIN REFLECTANCE IS ASSUMED AT 0.2,

APPENDIX A-2

(CONT.)

ATMOSPHERIC CLEARNESS AT 0.85. THIS DATA IS FOR CLEAR DAY CONDITIONS ON THE 21ST DAY OF MONTH.

WITH DAILY BEAM RADIATION, TRANSMITTED AND INCIDENT, FOR CLEAR DAY CONDITIONS, AND WITH AVERAGE DAY INCIDENT RADIATION, THE TRANSMITTED RADIATION FOR AN AVERAGE DAY IS FOUND:

$$\frac{\text{TRANSMITTED RADIATION CLEAR DAY}}{\text{INCIDENT RADIATION CLEAR DAY}} \times \text{INCIDENT RADIATION AVERAGE DAY} = \text{TRANSMITTED RADIATION AVERAGE DAY}$$

TRANSMITTANCY OF NORTH-FACING HEAT MIRROR IS ASSUMED AT .60. VALUES OF BTU/SAFT DAY TRANSMITTED THROUGH NORTH-FACING MIRROR APPEAR IN THE RIGHT HAND COLUMN ON THE NEXT PAGE. TO THE LEFT ARE VALUES FOR AVERAGE DAY INCIDENT RADIATION THROUGH EAST AND WEST-FACING HEAT MIRROR. THE FOLLOWING PAGES DETERMINE AVERAGE DAY TRANSMITTED TOTAL RADIATION FOR EAST AND WEST-FACING HEAT MIRROR.

APPENDIX A-2

<u>AVERAGE DAY INCIDENT RADIATION</u> BTU/SQ. FT. east, west-facing heat mirror DAY 0.20 ground reflectance					<u>TRANSMITTED</u> north-facing heat mirror DIFFUSE
	BEAM	DIFFUSE	REFLECTED	TOTAL	
JANUARY	220.8	107.6	47.5	375.9	95.6
FEBRUARY	306.6	154.9	71.0	532.5	131.7
MARCH	407.0	212.0	101.6	720.7	178.8
APRIL	473.8	281.4	132.6	887.8	241.5
MAY	587.3	299.4	162.0	1048.6	337.2
JUNE	632.4	338.8	181.7	1152.9	396.8
JULY	628.2	317.4	174.9	1120.6	349.7
AUGUST	548.2	286.6	148.6	983.4	257.2
SEPTEMBER	508.4	244.7	126.0	879.1	187.0
OCTOBER	387.7	182.5	89.0	659.2	138.0
NOVEMBER	209.3	124.7	50.3	384.4	98.8
DECEMBER	189.8	93.4	40.3	323.6	81.5

APPENDIX A-2

MONTH: JANUARY

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 220.8
DIFFUSE 155.1

DAILY BEAM RADIATION

TRANSMITTED 217.46
INCIDENT 377.98

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{220.8}{377.9} \times 217.46 = 127.03$$

DAILY DIFFUSE RADIATION

TRANSMITTED 69.68
INCIDENT 124.43

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{155.1}{124.4} \times 69.68 = 87.23$$

DAILY TOTAL RADIATION

TRANSMITTED 287.14
INCIDENT 502.42

AVERAGE DAY TRANSMITTED TOTAL: 214.3 $\frac{\text{BTU}}{\text{SQ FT. DAY}}$

APPENDIX A-2

MONTH: FEBRUARY

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 306.6
DIFFUSE 225.9

DAILY BEAM RADIATION

TRANSMITTED 316.88
INCIDENT 532.81

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{306.6}{532.8} \times 316.88 = 182.34$$

DAILY DIFFUSE RADIATION

TRANSMITTED 97.41
INCIDENT 173.95

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{225.9}{173.95} \times 97.41 = 126.5$$

DAILY TOTAL RADIATION

TRANSMITTED 414.29
INCIDENT 706.76

AVERAGE DAY TRANSMITTED TOTAL: 308.8 $\frac{\text{BTU}}{\text{SQ FT DAY}}$

APPENDIX A-2

MONTH: MARCH

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 407.0
DIFFUSE 313.6

DAILY BEAM RADIATION

TRANSMITTED 414.02
INCIDENT 671.68

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{407}{532} \times 414.02 = 316.7$$

DAILY DIFFUSE RADIATION

TRANSMITTED 133.75
INCIDENT 238.84

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{313.6}{238.8} \times 133.75 = 175.6$$

DAILY TOTAL RADIATION

TRANSMITTED 547.77
INCIDENT 910.52

AVERAGE DAY TRANSMITTED TOTAL: 492.3 $\frac{\text{BTU}}{\text{SQ FT DAY}}$

APPENDIX A-2

MONTH: APRIL

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 473.8
DIFFUSE 414.0

DAILY BEAM RADIATION

TRANSMITTED 486.62
INCIDENT 768.00

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{473.8}{768.0} \times 486.62 = 300.2$$

DAILY DIFFUSE RADIATION

TRANSMITTED 177.29
INCIDENT 316.59

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{414}{316.59} \times 177.29 = 231.84$$

DAILY TOTAL RADIATION

TRANSMITTED 663.91
INCIDENT 1084.59

AVERAGE DAY TRANSMITTED TOTAL: 532.0 ^{BTU}/_{SQ.FT. DAY}

APPENDIX A-2

MONTH: MAY

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 587.3
DIFFUSE 461.4

DAILY BEAM RADIATION

TRANSMITTED 498.69
INCIDENT 798.60

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{587.3}{798.6} \times 498.69 = 366.74$$

DAILY DIFFUSE RADIATION

TRANSMITTED 213.20
INCIDENT 380.72

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{461.4}{380.72} \times 213.2 = 258.38$$

DAILY TOTAL RADIATION

TRANSMITTED 711.83
INCIDENT 1179.33

AVERAGE DAY TRANSMITTED TOTAL:

625.1 $\frac{\text{BTU}}{\text{SQ FT. DAY}}$

APPENDIX A-2

MONTH: JUNE

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 632.4
DIFFUSE 520.5

DAILY BEAM RADIATION

TRANSMITTED 496.31
INCIDENT 797.66

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{632.4}{797.66} \times 496.3 = 393.48$$

DAILY DIFFUSE RADIATION

TRANSMITTED 228.54
INCIDENT 408.11

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{520.5}{408.11} \times 228.54 = 291.48$$

DAILY TOTAL RADIATION

TRANSMITTED 724.85
INCIDENT 1205.78

AVERAGE DAY TRANSMITTED TOTAL:

685.0 $\frac{\text{BTU}}{\text{SQ. FT. DAY}}$

APPENDIX A-2

MONTH: JULY

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 628.2
DIFFUSE 492.3

DAILY BEAM RADIATION

TRANSMITTED 483.28
INCIDENT 763.26

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{628.2}{763.26} \times 483.28 = 397.76$$

DAILY DIFFUSE RADIATION

TRANSMITTED 220.14
INCIDENT 393.11

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{492.3}{393.11} \times 220.14 = 276.69$$

DAILY TOTAL RADIATION

TRANSMITTED 703.42
INCIDENT 1156.38

AVERAGE DAY TRANSMITTED TOTAL:

674.5 BTU
S.F.
DAY

APPENDIX A-2

MONTH: AUGUST

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 548.2
DIFFUSE 435.2

DAILY BEAM RADIATION

TRANSMITTED 454.35
INCIDENT 719.14

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{548.2}{719.14} \times 454.35 = 346.35$$

DAILY DIFFUSE RADIATION

TRANSMITTED 189.34
INCIDENT 338.11

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{435.2}{338.11} \times 189.34 = 243.71$$

DAILY TOTAL RADIATION

TRANSMITTED 643.69
INCIDENT 1057.25

AVERAGE DAY TRANSMITTED TOTAL:

590.1 $\frac{\text{BTU}}{\text{SQ. FT. DAY}}$

APPENDIX A-2

MONTH: SEPTEMBER

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 508.4
DIFFUSE 370.7

DAILY BEAM RADIATION

TRANSMITTED 381.28
INCIDENT 626.48

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{508.4}{626.48} \times 381.28 = 307.4$$

DAILY DIFFUSE RADIATION

TRANSMITTED 140.64
INCIDENT 251.15

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{370.7}{251.15} \times 140.64 = 207.66$$

DAILY TOTAL RADIATION

TRANSMITTED 521.93
INCIDENT 877.63

AVERAGE DAY TRANSMITTED TOTAL:

577.1 $\frac{\text{BTU}}{\text{SQ FT DAY}}$

APPENDIX A-2

MONTH: OCTOBER

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 387.7
DIFFUSE 171.5

DAILY BEAM RADIATION

TRANSMITTED 312.04
INCIDENT 515.53

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{387.7}{515.53} \times 312.04 = 234.7$$

DAILY DIFFUSE RADIATION

TRANSMITTED 102.60
INCIDENT 183.21

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{171.5}{183.21} \times 102.60 = 96.04$$

DAILY TOTAL RADIATION

TRANSMITTED 414.64
INCIDENT 698.73

AVERAGE DAY TRANSMITTED TOTAL: 330.7 $\frac{\text{BTU}}{\text{SQ FT DAY}}$

APPENDIX A-2

MONTH: NOVEMBER

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM 209.3
DIFFUSE 175.0

DAILY BEAM RADIATION

TRANSMITTED 191.11
INCIDENT 355.60

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{209.3}{355.6} \times 191.11 = 112.5$$

DAILY DIFFUSE RADIATION

TRANSMITTED 70.18
INCIDENT 125.31

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{175.0}{125.31} \times 70.18 = 98.01$$

DAILY TOTAL RADIATION

TRANSMITTED 261.29
INCIDENT 480.91

AVERAGE DAY TRANSMITTED TOTAL:

212.5 $\frac{\text{BTU}}{\text{SQ. FT. DAY}}$

APPENDIX A-2

MONTH: DECEMBER

clear day data
east, west-facing heat mirror
0.20 ground reflectance

AVERAGE DAY INCIDENT RADIATION

BEAM /89.8
DIFFUSE /33.7

DAILY BEAM RADIATION

TRANSMITTED 172.37
INCIDENT 316.11

$\frac{\text{average day incident beam}}{\text{clear day incident beam}} \times \text{clear day transmitted beam}$

$$\frac{189.8}{316.11} \times 172.37 = 103.5$$

DAILY DIFFUSE RADIATION

TRANSMITTED 58.09
INCIDENT 103.72

$\frac{\text{average day incident diffuse}}{\text{clear day incident diffuse}} \times \text{clear day transmitted diffuse}$

$$\frac{133.7}{103.72} \times 58.09$$

DAILY TOTAL RADIATION

TRANSMITTED 230.46
INCIDENT 419.83

AVERAGE DAY TRANSMITTED TOTAL 178.4 $\frac{\text{BTU}}{\text{SQ. FT. DAY}}$

NORTH WEST UNIT

① $UA_{TOTAL} = 192 \text{ BTU/HOUR } ^\circ\text{F}$

② $\text{AVERAGE HOURLY INTERNAL GAINS} = 54,000 \text{ BTU/DAY}$

③ $\text{BALANCE POINT TEMPERATURE} = \frac{\text{AVERAGE INDOOR TEMPERATURE} - \left(\frac{\text{INTERNAL GAINS} \times \frac{1}{24} \text{ HOUR}}{UA_{TOTAL}} \right)}{1}$

$\text{BALANCE POINT TEMPERATURE} = 65^\circ - \frac{54,000 \text{ BTU/HOUR } ^\circ\text{F} \times \frac{1}{24} \text{ HOUR}}{192 \text{ BTU/HOUR } ^\circ\text{F}}$

$\text{BALANCE POINT TEMPERATURE} = 53^\circ$

$\text{MODIFIED UNIT LOAD} = \frac{\# \text{ DAY/MONTH FOR BALANCE POINT TEMPERATURE}}{1} \times UA_{TOTAL} \times 24 \text{ HOUR/DAY}$

$\text{MODIFIED UNIT LOAD} = \text{BTU/MONTH}$

APPENDIX A-2

MODIFIED UNIT LOAD:

MONTH	$53^\circ \text{ BALANCE POINT } ^\circ\text{DAY}$	$UA_{TOTAL} \times 24 \text{ HOUR/DAY}$	$192 \text{ BTU/HOUR } ^\circ\text{F}$	MONTHLY LOAD BTU/MONTH
JANUARY	738	192	24	3.4×10^6
FEBRUARY	633	192	24	2.9×10^6
MARCH	462.8	192	24	2.13×10^6
APRIL	160.2	192	24	$.738 \times 10^6$
MAY	19.4	192	24	$.089 \times 10^6$
JUNE	—	192	24	—
JULY	—	192	24	—
AUGUST	—	192	24	—
SEPTEMBER	2.8	192	24	$.005 \times 10^6$
OCTOBER	32.4	192	24	$.149 \times 10^6$
NOVEMBER	243.4	192	24	1.12×10^6
DECEMBER	620	192	24	2.86×10^6

INDIRECT GAIN

APPENDIX A-2

NORTHWEST
UNIT

8 NORTH-FACING FULL WINDOWS; 37% HEAT MIRROR
6 WEST-FACING CLERESTORIES; 9% HEAT MIRROR

MONTH	AVERAGE DAY TRANSMITTED RADIATION	AREA of GLASS	DAYS x MONTH	TOTAL MONTHLY TRANSMITTED RADIATION	MODIFIED UNIT LOAD	SOLAR HEATING FRACTION
JANUARY	NORTH: 95.6 (197)(31) WEST: 214.3 (48)(31)	.585 x 10 ⁶ .319 x 10 ⁶		.904 x 10 ⁶	3.4 x 10 ⁶	$\frac{.904}{3.4} = \underline{.27}$
FEBRUARY	NORTH: 131.7 (197)(28) WEST: 308.8 (48)(28)	.726 x 10 ⁶ .415 x 10 ⁶		1.14 x 10 ⁶	2.9 x 10 ⁶	$\frac{1.14}{2.9} = \underline{.39}$
MARCH	NORTH: 178.8 (197)(31) WEST: 492.3 (48)(31)	1.09 x 10 ⁶ .73 x 10 ⁶		1.82 x 10 ⁶	2.13 x 10 ⁶	$\frac{1.82}{2.13} = \underline{.85}$
NOVEMBER	NORTH: 98.8 (197)(30) WEST: 210.5 (48)(30)	.584 x 10 ⁶ .303 x 10 ⁶		.89 x 10 ⁶	1.12 x 10 ⁶	$\frac{.89}{1.12} = \underline{.79}$
DECEMBER	NORTH: 81.5 (197)(31) WEST: 178.4 (48)(31)	.498 x 10 ⁶ .265 x 10 ⁶		.763 x 10 ⁶	2.86 x 10 ⁶	$\frac{.763}{2.86} = \underline{.27}$

APPENDIX A-2

NORTHWEST
UNIT

ANNUAL SOLAR HEATING FRACTION

JANUARY FEBRUARY MARCH APRIL MAY SEPTEMBER OCTOBER NOVEMBER DECEMBER
 $.27(3.4 \times 10^6) + .39(2.9 \times 10^6) + .85(2.13 \times 10^6) + .738 \times 10^6 + .089 \times 10^6 + .005 \times 10^6 + .149 \times 10^6 + .77(1.12 \times 10^6) + .27(2.86 \times 10^6)$

SOLAR HEATING: 6.498×10^6 BTU/YEAR

UNIT LOAD: 13.391×10^6 BTU/YEAR

$$\text{ANNUAL SOLAR HEATING FRACTION} = \frac{6.498}{13.391} = \underline{\underline{.48\%}}$$

NORTHEAST UNIT

① $UA_{TOTAL} = 169 \text{ BTU/HOUR } ^\circ\text{F}$

② AVERAGE
HOURLY
INTERNAL
GAINS = $54,000 \text{ BTU/DAY}$

③
$$\text{BALANCE POINT TEMPERATURE} = \text{AVERAGE INDOOR TEMPERATURE} - \frac{(\text{INTERNAL GAINS} \times \frac{1}{24} \frac{\text{HOURS}}{\text{DAY}})}{UA_{TOTAL}}$$

$$\text{BALANCE POINT TEMPERATURE} = 65^\circ - \frac{(54,000 \times \frac{1}{24})}{169}$$

$$\text{BALANCE POINT TEMPERATURE} = 52^\circ$$

$$\text{MODIFIED UNIT LOAD} = \frac{\#^\circ\text{DAY/MONTH}}{\text{FOR BALANCE POINT TEMPERATURE}} \times UA_{TOTAL} \times 24 \frac{\text{HOURS}}{\text{DAY}}$$

$$\text{MODIFIED UNIT LOAD} = \text{BTU/MONTH}$$

APPENDIX A-2

MODIFIED UNIT LOAD:

MONTH	$^\circ\text{DAY @ } 5^\circ \text{ BALANCE POINT}$	$UA_{TOTAL} \text{ BTU/HOUR } ^\circ\text{F}$	$\times 24 \frac{\text{HOURS}}{\text{DAY}}$	MONTHLY LOAD BTU/MONTH
JANUARY	707	169	24	2.8×10^6
FEBRUARY	605	169	24	2.5×10^6
MARCH	432	169	24	1.7×10^6
APRIL	139	169	24	0.56×10^6
MAY	14.6	169	24	0.06×10^6
JUNE	—	169	24	—
JULY	—	169	24	—
AUGUST	—	169	24	—
SEPTEMBER	2.2	169	24	0.009×10^6
OCTOBER	37.6	169	24	0.15×10^6
NOVEMBER	216.6	169	24	0.88×10^6
DECEMBER	589	169	24	2.4×10^6

INDIRECT GAIN

APPENDIX A-2

NORTH EAST UNIT

8 NORTH-FACING FULL WINDOWS; 38% HEAT MIRROR
4 EAST-FACING CLERESTORIES; 9% HEAT MIRROR

MONTH	AVERAGE DAY TRANSMITTED × AREA of GLASS × DAYS RADIATION MONTH	TOTAL MONTHLY TRANSMITTED RADIATION	MODIFIED UNIT LOAD	SOLAR HEATING FRACTION
JANUARY	NORTH: 95.6 (197)(31) .584 × 10 ⁶ EAST: 214.3 (32)(31) .213 × 10 ⁶	0.796 × 10 ⁶	2.8 × 10 ⁶	$\frac{.798}{2.8} = \underline{.28}$
FEBRUARY	NORTH: 131.7 (197)(28) .726 × 10 ⁶ EAST: 308.8 (32)(28) .277 × 10 ⁶	1.003 × 10 ⁶	2.5 × 10 ⁶	$\frac{1.003}{2.5} = \underline{.40}$
MARCH	NORTH: 178.8 (197)(31) 1.09 × 10 ⁶ EAST: 492.3 (32)(31) .49 × 10 ⁶	1.58 × 10 ⁶	1.7 × 10 ⁶	$\frac{1.58}{1.7} = \underline{.93}$
NOVEMBER	NORTH: 98.8 (197)(30) .584 × 10 ⁶ EAST: 210.5 (32)(30) .202 × 10 ⁶	0.786 × 10 ⁶	0.88 × 10 ⁶	$\frac{.786}{.88} = \underline{.89}$
DECEMBER	NORTH: 81.5 (197)(31) .498 × 10 ⁶ EAST: 178.4 (32)(31) .177 × 10 ⁶	0.675 × 10 ⁶	2.4 × 10 ⁶	$\frac{.675}{2.4} = .28$

APPENDIX A-2

NORTHEAST
UNIT

ANNUAL SOLAR HEATING FRACTION

JANUARY FEBRUARY MARCH APRIL MAY SEPTEMBER OCTOBER NOVEMBER DECEMBER
.28(2.8x10⁶) + .40(2.5x10⁶) + .93(1.7x10⁶) + (.56x10⁶) + (0.06x10⁶) + (.009x10⁶) + (0.15x10⁶) + .89(.88x10⁶) + .28(2.4x10⁶)

SOLAR HEATING: 5.59 x 10⁶ BTU/YEAR

UNIT LOAD = 11.06 x 10⁶ BTU/YEAR

ANNUAL SOLAR HEATING FRACTION = $\frac{5.59 \times 10^6}{11.06 \times 10^6}$ or 50 %

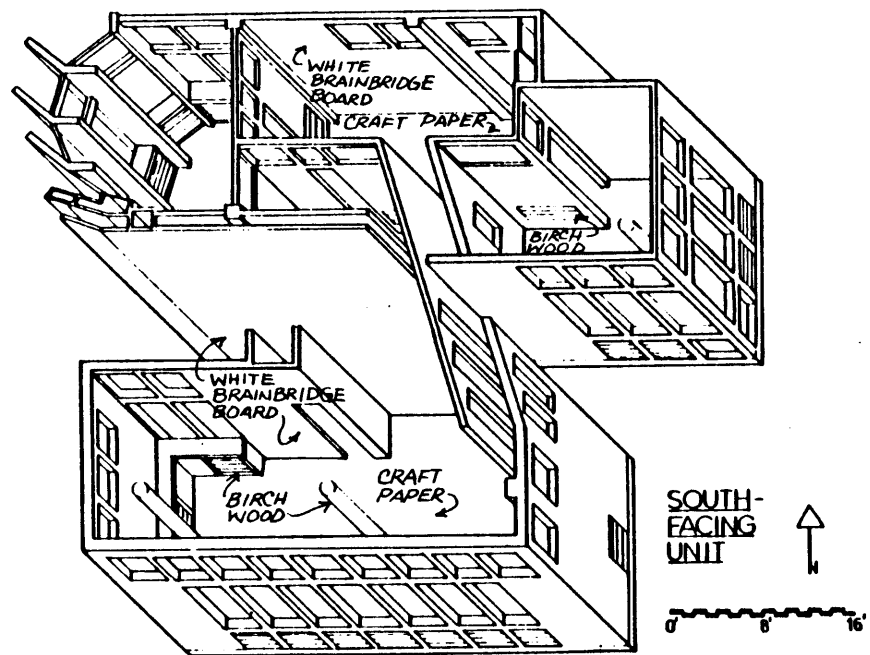
APPENDIX B LIGHT MODEL STUDIES:
DAYLIGHT LEVELS and QUALITY

APPENDIX B Light Model Studies: Daylight Levels and Quality

A model of a typical south-facing unit, constructed at $\frac{1}{2}" = 1'0"$, enables a remote control light meter to be inserted for the measurement of interior light levels. Evaluation of the qualitative aspects of daylighting design is accomplished using the same model; for a model of ample size allows the critical eye to register impressions of the spaces within through remote control imagination.

White architectural foam core backed with opaque white brainbridge board is used to model the high reflectance surfaces from working plane to ceiling. Below working plane the surfaces are mostly a light brown tone...craft paper and birch wood modelling the ventilation louvers below the insulated settees, and foam core backed with craft-paper modelling the floors. These darker tones simulate the effects furniture and floor coverings have on actual light levels. The model joints are sealed against light leaks with opaque tape.

Mullions are modelled to scale as are other obstructions to light such as exterior walls, fire



stairs, and reflective louvers which must be modelled in a space to depth ratio proportional to the actual size.

Glazing material is not modelled. Instead, light levels are reduced to 0.77 or $(0.88)^2$ of the actual readings in order to allow for transmission loss due to double glazing. Readings taken in interior areas, lit only by light transmission through interior transoms of single glazing, are multiplied by yet another factor of 0.88. And interior spaces gaining light from both exterior windows and interior transoms are reduced to 0.9 of 0.77 of the original reading.

Light levels are measured at working plane with the model outside oriented due south and horizontal to the ground so as to not alter the amount of diffuse radiation from the sky vault. In addition to registering light levels within the model, simultaneous readings are taken outside with a light meter, protected from direct sunlight but exposed to the sky vault.

The effect of a combination lightshelf-overhang, louvers, or louvers-lightshelf are studied for south-facing sun control. The effect of various windows on light levels and the effect

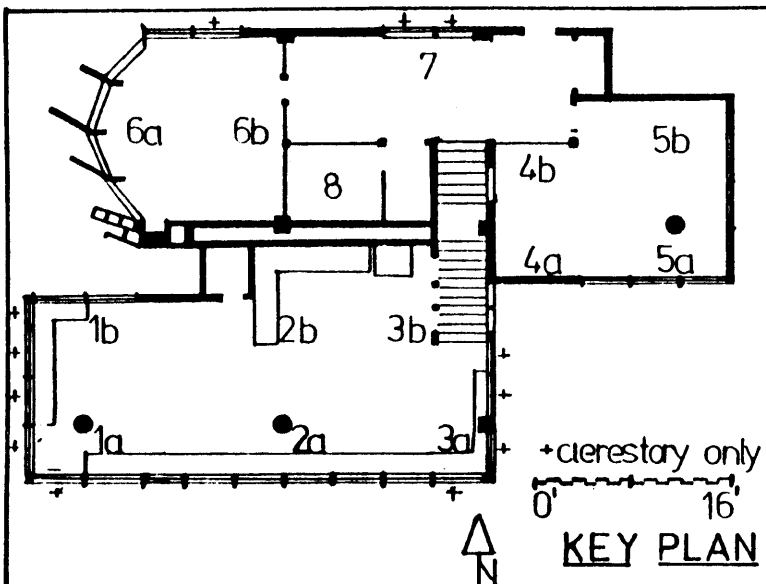
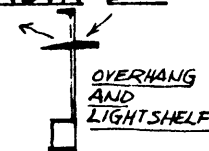
of exterior wall reflectances into the interior are also investigated.

APPENDIX B-1

exterior
daylight
conditions

MARCH 7
7:15 A.M.

CLOUDY
450 fc.



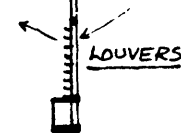
position	light level (fc)	daylight factor	light level by a	note
1a	57	0.13	.89	SOUTH-FACING WINDOWS SHADED WITH 1/2' WIDE OVERHANG ON EXTERIOR WITH MATTE WHITE SURFACE; REFLECTIVE 1/2' WIDE LIGHT-SHELF WITHIN; BOTH IMMEDIATELY BELOW CLERESTORY.
1b	51	0.11		
2a	43	0.10	.95	
2b	41	0.09		
3a	43	0.10	1.00	
3b	43	0.10		

APPENDIX B-2

exterior
daylight
conditions

MARCH 7
7:00 AM.

CLOUDY
325 fc.

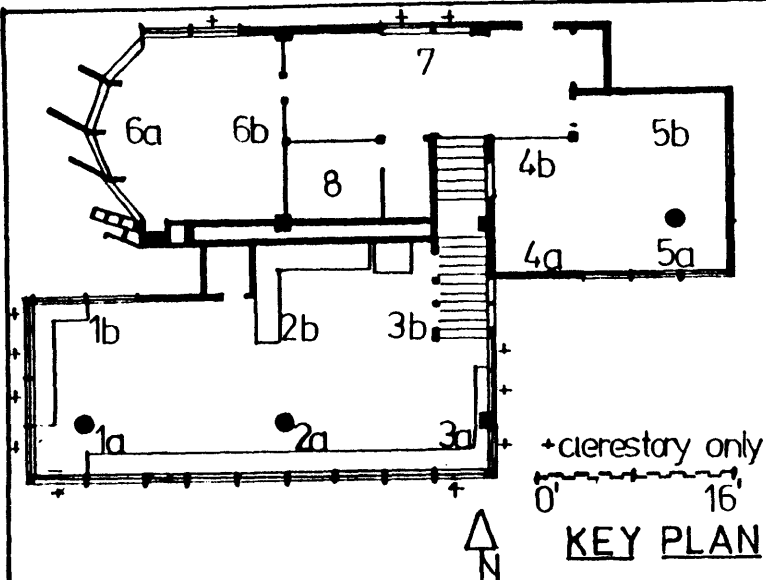


THE OVERHANG AND LIGHTSHELF HAVE BEEN REPLACED BY LOUVERS OF 1 TO 1.9 SPACE TO DEPTH RATIO; IN MIDHEIGHT, SOUTH-FACING WINDOWS.

WITH A DECREASE OF 125 $\frac{1}{2}$ OUTSIDE, THE RELATIVE LIGHT LEVEL INSIDE HAS INCREASED.

CONTRAST FROM FRONT TO BACK OF ROOM HAS INCREASED DUE TO THE REMOVAL OF THE LIGHT SHELF WHICH THROWS LIGHT TO THE BACK OF THE SPACE, AND THE REMOVAL OF THE OVERHANG WHICH SHADES THE IMMEDIATE WINDOW WALL.

LIGHT LEVEL IN THE AREA OF THE KITCHEN (2b), IS LESS THAN ANYWHERE IN THIS SPACE.



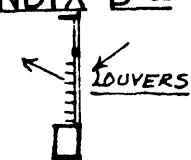
position	light level (fc)	daylight factor	light level by a	note
1a	56	0.17	0.96	
1b	54	0.17		
2a	54	0.17	0.78	
2b	42	0.13		
3a	56	0.17	0.80	
3b	45	0.14		

APPENDIX B-2

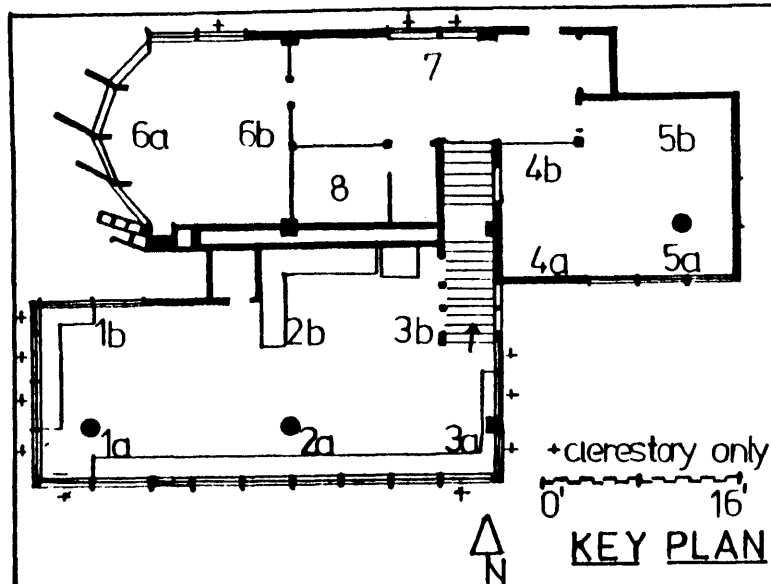
exterior
daylight
conditions

MARCH 7
7:45 A.M.

CLOUDY
475 fc.



SOUTH-FACING MIDHEIGHT WINDOWS
WITH LOUVERS OF 1 TO 1.9 SPACE TO
DEPTH RATIO.



MORE EVEN DISTRIBUTION OF LIGHT OCCURS
IN THIS ROOM THAN THE SOUTH-FACING
ROOM DOWNSTAIRS. THIS MAY BE
EXPLAINED BY:

THE DEPTH OF THIS ROOM IS LESS THAN
THE LOWER ROOM;

THE WINDOWS FACING EAST ARE FULL
WINDOWS, FROM WORKING PLANE TO
CEILING AS OPPOSED TO THE SIDE
CLERESTORIES DOWNSTAIRS. OVERHEATING
AND GLARE DUE TO LOW SUN ANGLES
ARE NOT A PROBLEM HERE, AS THEY
OVERLOOK THE DAYLIT, INTERIOR COMMON
SPACE.

position	light level (fc)	daylight factor	light level by a	note
4a	62	0.13	0.90	
4b	56	0.12		
5a	70	0.15	0.93	
5b	65	0.14		

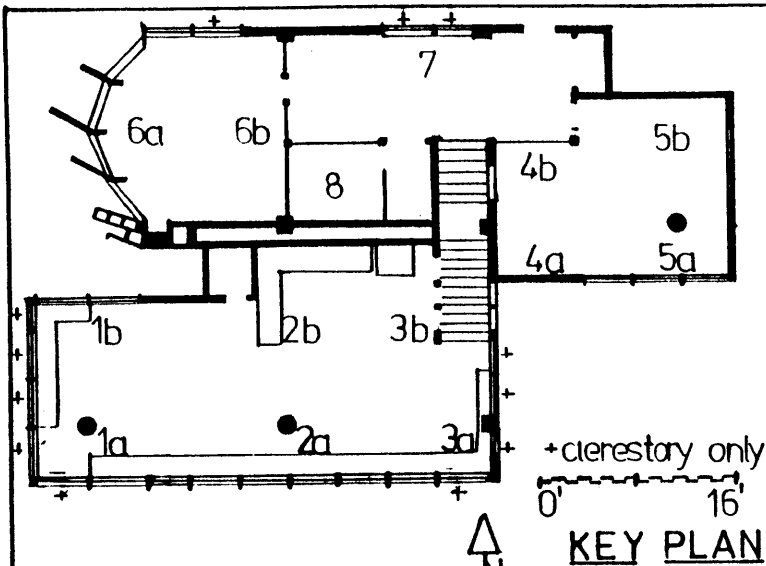
APPENDIX B-2

exterior
daylight
conditions

MARCH 5
10:00 A.M.

CLOUDY
* 700 fc.

LOUVERS
RAISED



THE LOUVERS ARE REMOVED TO
SIMULATE THE RAISING OF THEM
ON A CLOUDY DAY.

position	* light level (fc)	* daylight factor	* light level by a	note
1a	130fc	0.19	0.91	
1b	119fc	0.17		
2a	119fc	0.17	0.76	
2b	91fc	0.13		
3a	120fc	0.17	0.82	
3b	98fc	0.14		

THE DAYLIGHT FACTOR INCREASES ONLY
SLIGHTLY WHEN THE LOUVERS ARE
RAISED,

THERE APPEARS TO BE LESS CONTRAST
BETWEEN FRONT AND BACK OF ROOM
WHICH MAY NOT ACTUALLY HAPPEN
AS LOUVERS ARE NOT MODELLED TO
REFLECT LIGHT BACK @ 30° ANGLE.

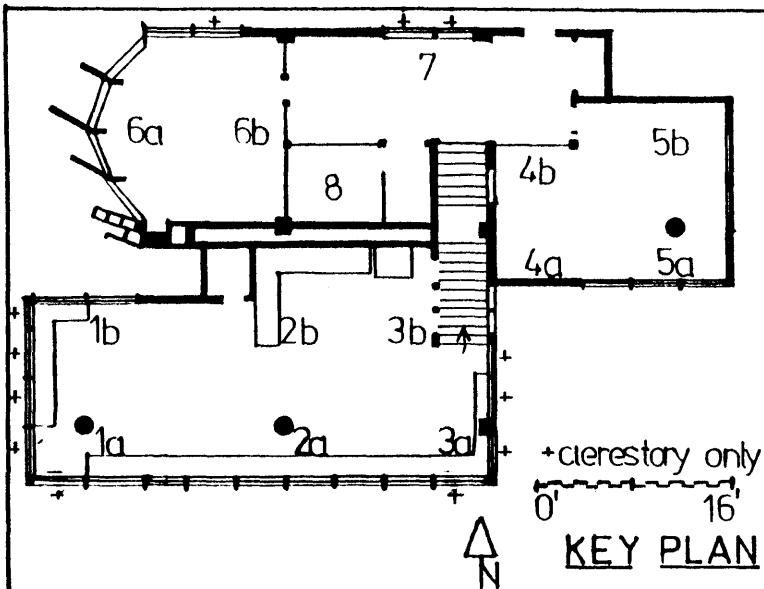
* NOTE INCREASED LIGHTING UNIFORMITY WITH
ADDITION OF LIGHT SHELF, FOLLOWING PAGE.

APPENDIX B-3

exterior
daylight
conditions

MARCH 7
8:00 AM.

CLOUDY
* 700 fc.



THE LOUVERS ARE REMOVED TO SIMULATE THE RAISING OF THEM ON A CLOUDY DAY. A LIGHTSHELF, 1 1/2' WIDE WITH REFLECTIVE SURFACE IS PLACED INSIDE, IMMEDIATELY BELOW THE CLERESTORY.

position	* light level (fc)	* daylight factor	* light level b/a	note
1a	126	0.18	0.95	
1b	120	0.17		
2a	108	0.15	1.00	
2b	105	0.15		
3a	104	0.15	0.96	
3b	100	0.14		

ALTHOUGH THE LIGHT LEVEL AT THE WINDOW DECREASES SLIGHTLY, THE DISTRIBUTION FROM FRONT TO BACK OF ROOM IMPROVES AS THE LIGHT SHELF TAKES LIGHT FROM THE WINDOW PLANE TO THROW IT FURTHER INTO THE SPACE.

THE LIGHT SHELF HELPS ESPECIALLY AT THE KITCHEN AREA, 2b.

FOR COMPARISON WITH/WITHOUT LIGHTSHELF,
* EXTERIOR LIGHT LEVEL IS 700fc.

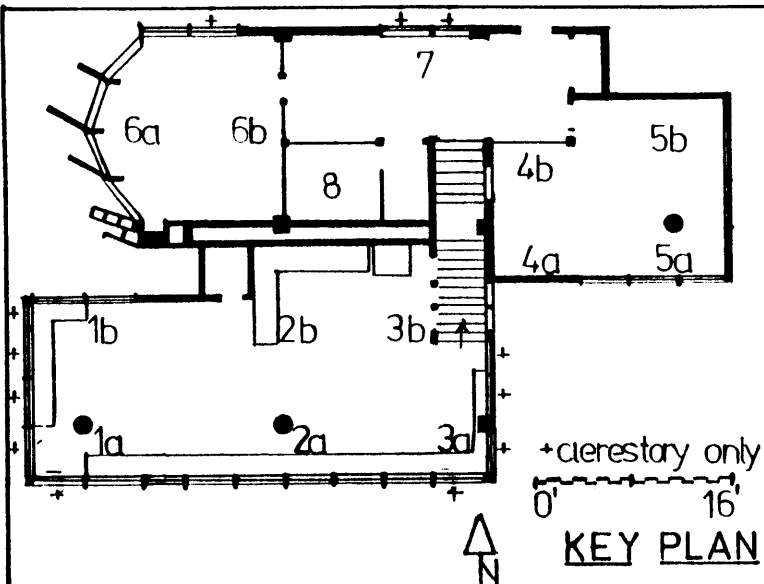
APPENDIX B-3

exterior
daylight
conditions

MARCH 7
7:30 A.M.

CLOUDY
475 fc.

LOUVERS
RAISED
AND
LIGHTSHELF



THE LOUVERS ARE REMOVED TO SIMULATE THE RAISING OF THEM ON A CLOUDY DAY. A LIGHTSHELF, $1\frac{1}{2}'$ WIDE WITH REFLECTIVE SURFACE IS PLACED INSIDE, IMMEDIATELY BELOW THE CLERESTORY.

AGAIN, THE UNIFORMITY OF LIGHT IS QUITE GOOD, THE LIGHT SHELF BORROWING SOME OF THE EXCESS LIGHT AT THE WINDOW PLANE AND LENDING IT TO THE DARKER REACHES OF THE ROOM.

position	light level (fc)	daylight factor	light by a	note
1a	86	0.18	0.92	
1b	79	0.17		
2a	°67	°0.14	1.00	
2b	°67	°0.14		
3a	67	0.14	0.95	
3b	64	0.13		

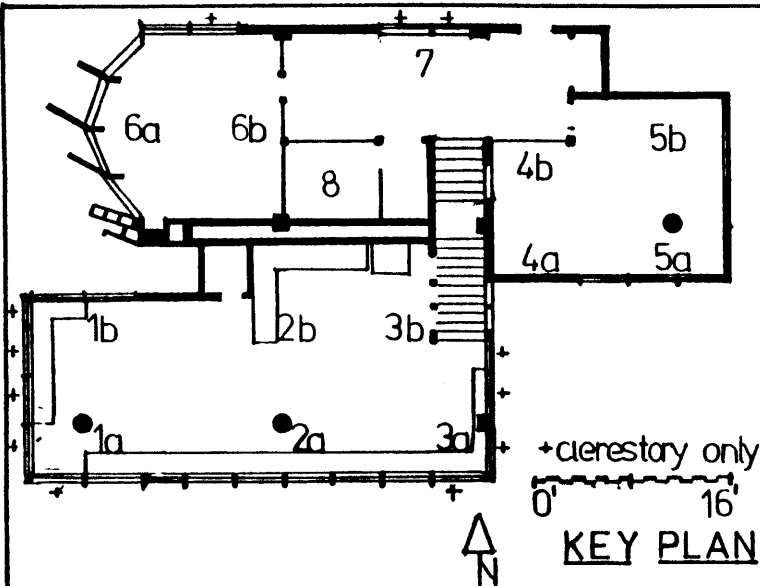
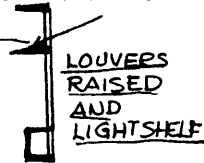
° WITH LOUVERS INSERTED AND LIGHTSHELF REMAINING, LIGHT LEVELS @ 2a AND 2b DROP TO 43 fc., 0.10 DAYLIGHT FACTOR.

APPENDIX B-4

exterior
daylight
conditions

MARCH 7
8:15 AM

CLOUDY
800 fc



THE LOUVERS ARE REMOVED TO SIMULATE THE RAISING OF THEM ON A CLOUDY DAY. A REFLECTIVE LIGHT SHELF IS PLACED INSIDE, IMMEDIATELY BELOW THE CLERESTORY.

THE CLERESTORY TO THE EAST, THE ONE TO THE WEST, AND THE FULL WINDOW TO THE NORTH ARE COVERED IN TURN TO DETERMINE THE AMOUNT OF LIGHT EACH CONTRIBUTES TO THE SPACE.

THE CONTRIBUTION OF THE EAST, NORTH, AND EVEN WEST-FACING WINDOWS IS NEGLIGIBLE CONSIDERING ONLY FOOTCANDLES. BUT THESE WINDOWS REDUCE CONTRAST BETWEEN OTHER WINDOWS AND THEIR ADJACENT SURFACES, ADMIT CHANGING LIGHT PATTERNS; THE NORTH-FACING OFFERS A VIEW.

position	light level (fc)	daylight factor	light by %	note
BETWEEN 2a AND 2b	108	.14		
	97	.12		
SAME	116	.15		
	116	.15		
BETWEEN 3a AND 3b	120	.15		
	116	.15		
BETWEEN 1a AND 1b	155	.19		
	151	.19		

ALL WINDOWS CLEAR.

ALL OF CLERESTORY TO WEST COVERED.

ALL WINDOWS CLEAR.

ALL OF CLERESTORY TO EAST COVERED.

ALL WINDOWS CLEAR.

ALL OF CLERESTORY TO EAST COVERED

ALL WINDOWS CLEAR

WINDOW TO NORTH COVERED

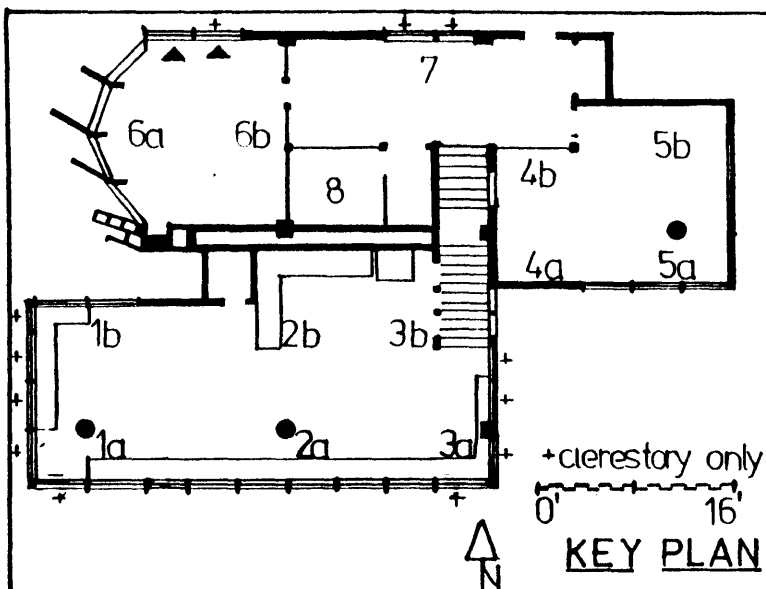
APPENDIX B-4

exterior
daylight
conditions

MARCH 7
7:20 A.M.

CLOUDY
450 fc

SUN CONTROL
FOR WEST-
FACING
WINDOWS:
FIXED VERTICAL
FINS.



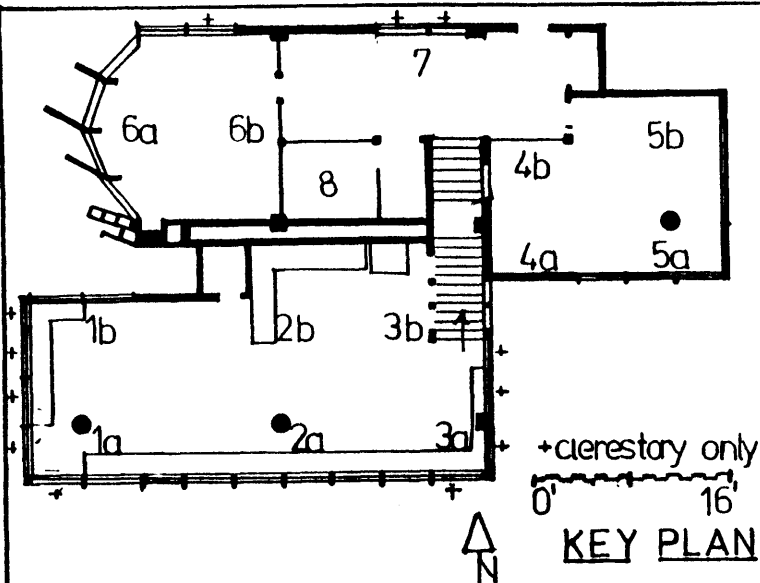
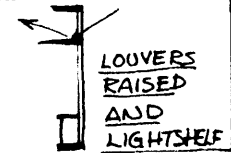
position	light level (fc)	daylight factor	light level by a	note
6a	89	0.19	0.78	ALL WINDOWS CLEAR.
6b	69	0.15		
6a	74	0.16	0.68	WITH ▲ NORTH WINDOWS OBSTRUCTED OF INCOMING LIGHT, THE INTERIOR LIGHT LEVELS IN THIS ROOM DECREASE BY 15 fc. AT THE WINDOW AND BY 19 fc. IN THE BACK. LIGHT DISTRIBUTION SUFFERS.
6b	50	0.11		

APPENDIX B-4

exterior
daylight
conditions

MARCH 7
8:15 AM.

CLOUDY
800 fc



THE LOUVERS ARE RAISED, THE LIGHT-SHELF IN PLACE.

THE EAST-FACING WINDOWS UPSTAIRS ARE COVERED TO DETERMINE THEIR FOOTCANDLE CONTRIBUTION TO THE IMMEDIATE SPACE AND ENTRY.

THESE WINDOWS ADD SOME LIGHT TO THE IMMEDIATE ROOM AS THEY ARE FULL WINDOWS, CONSTITUTING $\frac{1}{2}$ THE WINDOW AREA FOR THIS ROOM.

position	light level (fc)	daylight factor	light by a	note
BETWEEN 4a AND 5a	143	.18		
4b 5b	130	.16		
	120	.15		
7	32	.04		
	29	.04		

ALL WINDOWS CLEAR

ONE EAST-FACING WINDOW COVERED

TWO EAST-FACING WINDOWS COVERED

ALL WINDOWS CLEAR

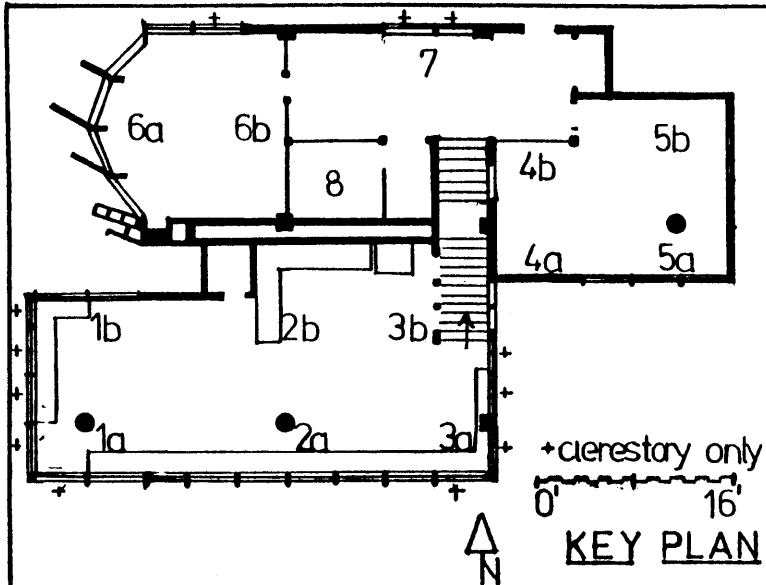
TWO EAST-FACING WINDOWS COVERED

APPENDIX B-4

exterior
daylight
conditions

MARCH 7
2:30 P.M.

PARTLY
CLOUDY
SUNNY.
LIGHT HAZE
1,100 fc.



ASIDE FROM ITS OWN CLERESTORY,
THE ENTRY GAINS A SIGNIFICANT
AMOUNT OF LIGHT THROUGH TRANSOMS
FROM THE UPSTAIRS SOUTH-FACING
WINDOW. A BIT IS OBTAINED
FROM THE WEST, NONE FROM DOWN-
STAIRS.

position	light level (fc)	daylight [†] factor	light by level	note
7	104	0.09		
	77	0.07		
	104	0.09		
	95	0.08		

ALL WINDOWS CLEAR.

SOUTH-FACING WINDOW UPSTAIRS (@ 4a AND 5a)
COVERED.

SOUTH-FACING WINDOW DOWNSTAIRS (@ 1a, 2a, AND 3a)
COVERED

WEST-FACING WINDOW (@ 6a) COVERED.

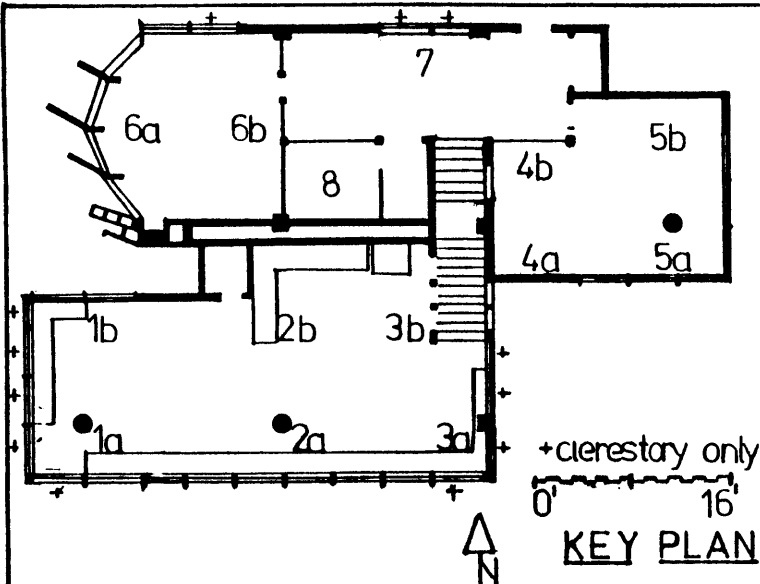
[†] MAY BE TOO LIGHT CLOUD COVER TO BE ACCURATE.

APPENDIX B-4

exterior
daylight
conditions

MARCH 7
7:45 A.M.

CLOUDY
475 fc.



THE CLERESTORY AT THE ENTRY (7)
PLAYS A SIGNIFICANT ROLE IN LIGHTING
BOTH THE ENTRY AND THE BATH. AT
SUCH LOW LIGHT LEVELS, SEVERAL
FOOTCANDLES ARE SIGNIFICANT.

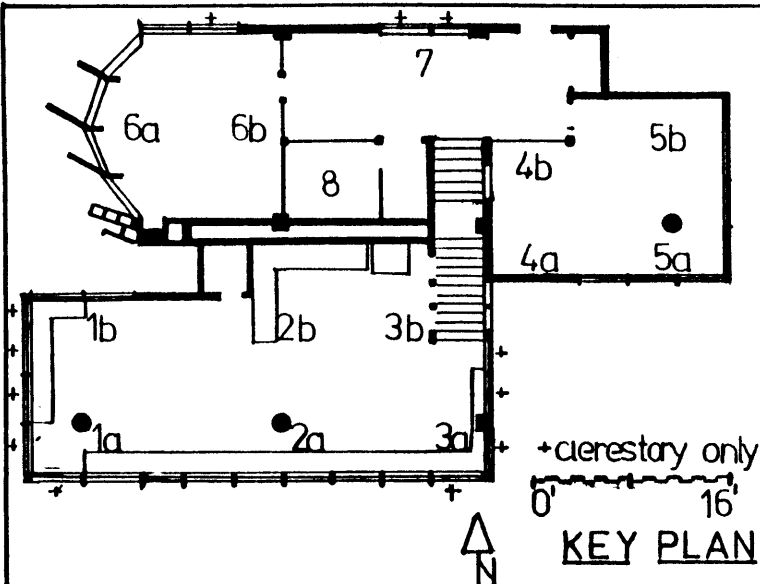
position	light level (fc)	daylight factor	light level $\frac{b}{a}$	note
7	27	0.06		ALL WINDOWS CLEAR. CLERESTORY AT ENTRY COVERED.
	15	0.03		
8	12	0.03		ALL WINDOWS CLEAR CLERESTORY AT ENTRY COVERED
	8	0.02		

APPENDIX B-4

exterior
daylight
conditions

MARCH 7
2:30 P.M.

PARTLY
CLOUDY,
SUNNY;
LIGHT HAZE
1,200fc.



THE WEST-FACING WINDOW LENDS
CONSIDERABLE LIGHT TO THE BATHROOM.

position	light level (fc)	daylight [†] factor	light by a	note
8	44	0.04		
	35	0.03		
	42	0.04		
	44	0.04		

ALL WINDOWS CLEAR

WEST-FACING WINDOW (@ 6a) COVERED.

SOUTH-FACING WINDOW (@ 4a AND 5a) COVERED.

SOUTH-FACING WINDOW (@ 1a, 2a, 3a) COVERED.

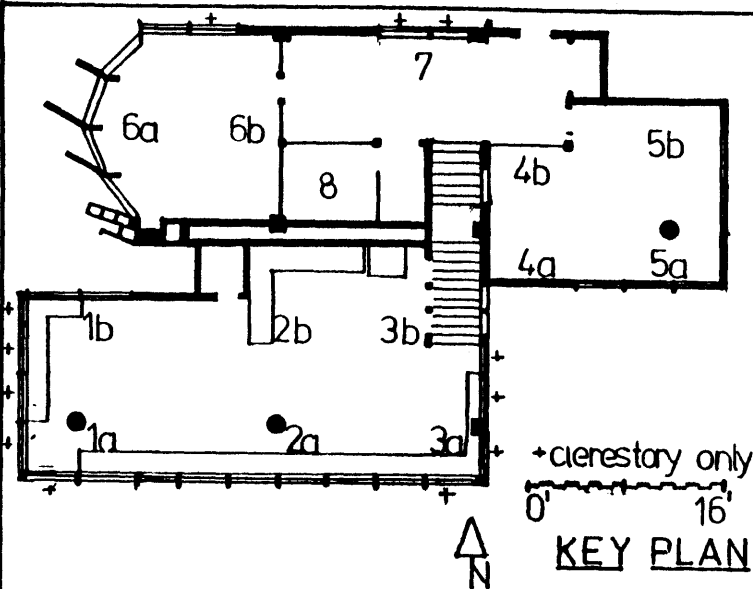
† MAY BE TOO LIGHT CLOUD COVER TO BE ACCURATE.

APPENDIX B-5

exterior
daylight
conditions

MARCH 7
2:30 P.M.

PARTLY
CLOUDY
SUNNY
LIGHT HAZE
1,200 SC.



THE WALL SURFACE PARALLEL TO THE NORTH WALL OF THIS PARTICULAR UNIT REFLECTS AFTERNOON SUN INTO THE UPSTAIRS PORTION OF THE UNIT. ITS CONTRIBUTION IS NOTABLE.

position	light level (fc)	daylight factor	light level $\frac{b}{a}$	note
7	97	0.08		WITH WHITE SURFACE TO NORTH REFLECTING SOUTHWEST LIGHT TO WINDOWS.
	83	0.07		
	70	0.06		
8	62	0.05		WITH WHITE SURFACE TO NORTH REFLECTING SOUTHWEST LIGHT TO WINDOWS.
	42	0.04		
	33	0.03		
				WITH GOLD SURFACE.
				WITH NO SURFACE.

APPENDIX C LIGHT MODEL STUDIES:
EAST and WEST-FACING SUN CONTROL

APPENDIX C Light Model Studies: East and West-
Facing Sun Control

The model of a typical south-facing unit, described in Appendix B, is used to help design the east and west-facing building facades. The rectangular kitchen-living-dining portion of this particular unit does not suffer from the glare and heat gain problems caused by low sun altitude angles; for glazing is limited to the clerestory portion of the wall with one window for view below working plane. As determined in Appendix B-4, the west-facing clerestory is hardly needed for interior light levels, but is useful in decreasing the contrast between other windows and their adjacent wall surfaces as well as for controlling the vector/scalar ratio.

The rounded bay element upstairs, however, demands more than just clerestory glazing, as two of the unit's bays depend on this west-facing facade for light and view. Thus, both clerestory and midheight portions are double-glazed. With almost 100 square feet of glazing on this wall, sun control is of paramount concern.

Although exterior adjustable vertical louvers

permit tracking the sun for more refined shading, the turbulent winds at this height deny such an option. Interior vertical louvers, much like the horizontal blinds used with the midheight south-facing windows, do not lend a desired image of solidity to the round, almost trunk-like vertical element. Building-scale vertical fins not only appear stable and permanent, but control low morning and evening sun angles, permit view, and allow entry of light diffused by multiple reflections off the matte, highly reflective fin surfaces. In addition, their size permits them to rise from the ground and extend the height of the building as lofty shafts. Their size is commensurate with that of the ventilation stacks which extend from an inlet on the second level of each unit to the outlet, four levels above. As such, some of the vertical shading fins couple as stack-effect ventilators, an integration of natural environmental control devices.

The west-facing semicircular bay has a distinct advantage over a west-facing planar wall

in that as the sun drops, not all of the glazing is inundated by direct sun. Some of the glazing receives glancing blows of light, while some is in the shade; for all windows do not face directly west, but wrap around to the north and south. This makes the shading effectiveness of various vertical fin arrangements somewhat difficult to predict due to complex angles. This is where the model is useful; for in combination with a heliodon and beam light source, the play between sun angles and building facade can be studied.

The light model, described in Appendix B, is placed on a heliodon adjusted in relation to the stationary light source to simulate a variety of critical sun angles from 6 A.M. and 6 P.M. on June 21 to 9 A.M. and 3 P.M. on December 21. Three facade designs are studied.

The first design assumes each of five vertical fins serve as a ventilation stack for the four separate units in each of the five neighborhoods. This establishes a stepped pattern on the bay facade. The south-most fin is oriented straight west, with the assumption that the sun setting south of west is blocked and that the equinox sun, setting due west, strikes the window at a shallow

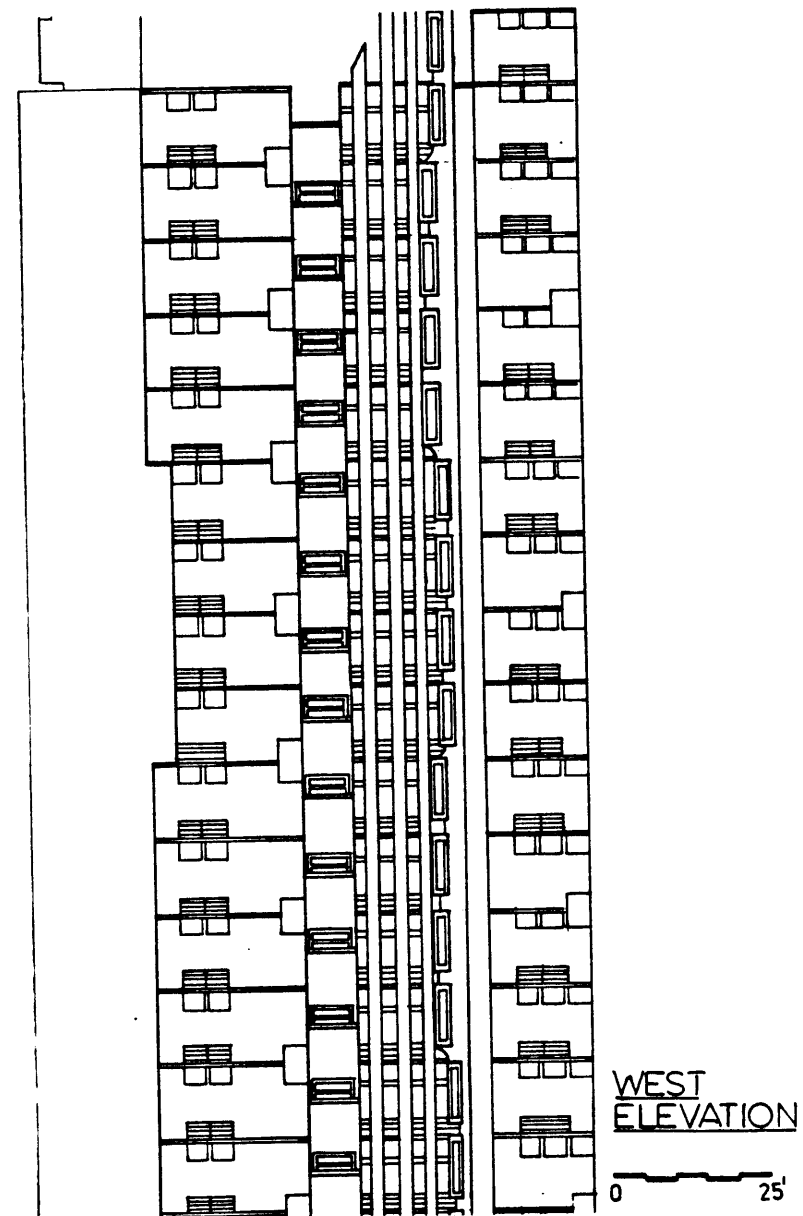
angle, not directly penetrating the space. The rays of the summer sun to the north are practically parallel to these windows angled south of west. The remaining four fins are oriented 35° north of due west. The setting sun is filtered from the room for most of the year except near summer solstice, when it sets well to the north of west. Although the windows and fins are so oriented for a targetted shot of direct sunlight at this time, the summer sun drifts high in the sky vault all day, preventing problems with glare and heat gain until night before the sun sets. The period of direct solar penetration is fleeting, for the sun drops quickly to the northwest.

The direct west orientation of the two south-most fins allows direct evening sun to penetrate the south-most window $3/4$ of the year. And the two diverse fin orientations, west and north of west, are disconcerting in appearance. The use of each fin as a ventilation stack for one neighborhood requires five fins. This seems to crowd the windows, the rooms inside appearing dark. Such esthetic factors ask for a new approach.

The second design assumes that only the south-most fin serves as a ventilation stack, forming one

wall of the building crenelation at which the auxiliary heating system is exhausted. This fin is wider than the rest, accomodating the ventilation stacks of two neighborhoods at once, one stack with four inlets, one with four outlets. This results in a staggering pattern, leaving more freedom in the design of the remaining vertical fins. All fins are oriented to the northwest, cutting out much of the low angle sun until summer when the sun's trajectory is high, dropping quickly behind the horizon in the evening. Only three other fins are placed on the bay to avoid the appearance of clutter and for more diffuse light penetration. Although a perceptual improvement over the first trial, it does not test as well as the former.

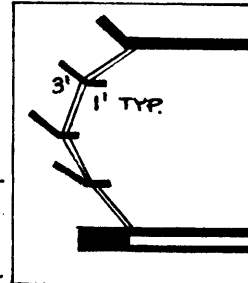
The third design is very similar to the second. Sun control was made more effective by increasing the exterior depth of the fin from 3' to 4'. Number, spacing, and fin orientation are constant.



DESIGN # 1

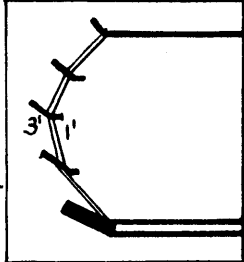
APPENDIX C

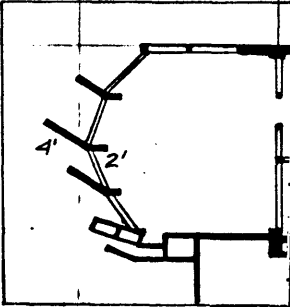
CRITICAL TIME



VERTICAL FINS ORIENTED TO NORTH WEST
EXCEPT SOUTHWEST FIN. MOST SUN
ANGLES TO SOUTHWEST WINDOW
ARE GLANCING.

DEC. 21 9:00am 3:00pm	NO DIRECT SUN PENETRATION
JAN. & NOV. 21 8:30am 3:30pm	NO DIRECT SUN PENETRATION
FEB. & OCT. 21 8:00am 4:00pm	NARROW SHAFT THROUGH SOUTHWEST BAY; DEEP SUN PENETRATION; 60% SHADING ON THIS WINDOW; 90% SHADING ON TOTAL BAY.
MAR. & SEPT. 21 7:30am 4:30pm	PARTIAL SHAFT OF SUNLIGHT THROUGH SOUTHWEST BAY; 30% SHADING ON THIS WINDOW; 85% SHADING ON TOTAL BAY; SUN AT GLANCING ANGLE TO GLASS.
APR. & AUG. 21 6:30am 5:30pm	FULL SHAFT OF SUNLIGHT THROUGH TWO SOUTHWEST WINDOWS; NO SHADING ON THESE WINDOWS; >50% SHADING ON TOTAL BAY; SUN AT GLANCING ANGLE TO GLASS.
MAY & JULY 21 6:00 am 6:00 pm	PARTIAL SHAFTS OF SUNLIGHT THROUGH ALL WINDOWS; NARROW SHAFT THROUGH NORTH-FACING WINDOW; ~30% SHADING ON TOTAL BAY SUN AT GLANCING ANGLE TO SOUTHWEST GLASS.
JUNE 21 6:00am 6:00pm	ALMOST FULL SHAFTS OF SUNLIGHT THROUGH ALL WINDOWS; NARROW SHAFT THROUGH NORTH-FACING WINDOW; >30% SHADING ON TOTAL BAY SUN AT GLANCING ANGLE TO SOUTHWEST GLASS.

DESIGN # <u>2</u>			APPENDIX <u>C</u>
<u>CRITICAL TIME</u>			VERTICAL FINS ORIENTED TO NORTHWEST; ONLY LOW, LATE, FLEETING SUMMER SUN ENTERS SPACE.
DEC. 21 9:00am 3:00pm	NO DIRECT SUN PENETRATION		
JAN. & NOV. 21 8:30am 3:30pm	NO DIRECT SUN PENETRATION		
FEB. & OCT. 21 8:00am 4:00pm	NARROW SHAFT THROUGH SOUTHMOST BAY		
MAR. & SEPT. 21 7:30am 4:30pm	PARTIAL SHAFTS OF SUNLIGHT THROUGH TWO SOUTHMOST BAYS;		
APR. & AUG. 21 6:30am 5:30pm	PARTIAL SHAFTS OF SUNLIGHT THROUGH ALL WINDOWS; ~50% SHADING ON TOTAL BAY. SUN AT GLANCING ANGLE TO SOUTHMOST GLASS		
MAY & JULY 21 6:00 am 6:00 pm	PARTIAL SHAFTS OF SUNLIGHT THROUGH ALL WINDOWS; ~20% SHADING ON TWO NORTHMOST WINDOWS; ~30% SHADING ON TWO SOUTHMOST WINDOWS SUN AT GLANCING ANGLE TO SOUTHMOST GLASS; PENETRATION IS NEGLIGIBLE		
JUNE 21 6:00am 6:00pm	SHAFTS OF SUNLIGHT THROUGH ALL WINDOWS; ~15% SHADING ON TWO NORTHMOST WINDOWS; ~20% SHADING ON TWO SOUTHMOST WINDOWS SUN AT GLANCING ANGLE TO SOUTHMOST GLASS.		

DESIGN # <u>3</u>		APPENDIX C	
CRITICAL TIME			VERTICAL FINS ORIENTED TO NORTHWEST; ONLY LOW, LATE FLEETING SUMMER SUN ENTERS SPACE.
DEC. 21 9:00am 3:00pm	NO DIRECT SUN PENETRATION		
JAN. & NOV. 21 8:30am 3:30pm	NO DIRECT SUN PENETRATION		
FEB. & OCT. 21 8:00am 4:00pm	NO DIRECT SUN PENETRATION		
MAR. & SEPT. 21 7:30am 4:30pm	NARROW SHAFT OF SUNLIGHT THROUGH TWO SOUTHMOST BAYS; 75% SHADING ON EACH WINDOW; 87.5% SHADING ON TOTAL BAY; SUN AT GLANCING ANGLE TO GLASS.		
APR. & AUG. 21 6:30am 5:30pm	NARROW SHAFT OF SUNLIGHT THROUGH ALL WINDOWS; 60% SHADING ON EACH WINDOW; 60% SHADING ON TOTAL BAY SUN AT GLANCING ANGLE TO ALL GLASS EXCEPT WINDOW THIRD FROM SOUTH.		
MAY & JULY 21 6:00 am 6:00 pm	PARTIAL SHAFTS OF SUNLIGHT THROUGH ALL WINDOWS; 25% SHADING ON TWO NORTHMOST WINDOWS; 50% SHADING ON TWO SOUTHMOST WINDOWS; 37.5% SHADING ON TOTAL BAY; PENETRATION THROUGH SOUTH WINDOWS IS NEGLIGIBLE AS LIGHT IS COMING IN PARALLEL TO THE WINDOW PLANE.	5 P.M. (1 HOUR EARLIER)	NARROW SHAFTS OF LIGHT THROUGH EACH WINDOW.
JUNE 21 6:00am 6:00pm	SHAFTS OF SUNLIGHT THROUGH ALL WINDOWS; 20% SHADING ON TWO NORTHMOST WINDOWS; 30% SHADING ON TWO SOUTHMOST WINDOWS; 27.5% SHADING ON TOTAL BAY; PENETRATION THROUGH SOUTH WINDOWS IS NEGLIGIBLE AS LIGHT IS COMING IN PARALLEL TO THE WINDOW PLANE	4 P.M. TO 5 P.M. (1 HOUR EARLIER)	NARROW SHAFTS OF LIGHT THROUGH EACH WINDOW.

APPENDIX D RECOMMENDED MINIMUM DAYLIGHT FACTORS

RECOMMENDED MINIMUM DAYLIGHT FACTORS

APPENDIX D

"IN BUILDINGS WITH SIDE LIGHTING ONLY, THE DAYLIGHT FACTOR AT POINTS REMOTE FROM THE WINDOW SHOULD NOT BE LESS THAN THE VALUE IN THE TABLE FOR THE LOCATION. THESE RECOMMENDED MINIMUM DAYLIGHT FACTORS ENSURE THAT THE BUILDING WILL APPEAR TO BE WELL LIGHTED PROVIDED THAT ROOM SURFACES HAVE SUITABLE REFLECTANCES."

LIVING ROOMS: A DAYLIGHT FACTOR OF NOT LESS THAN 1 PERCENT SHOULD BE PROVIDED OVER AT LEAST 8 m^2 AND SHOULD EXTEND TO AT LEAST HALF THE DEPTH OF THE ROOM FROM THE MAIN WINDOW.

BEDROOMS: A DAYLIGHT FACTOR OF NOT LESS THAN 0.5 PERCENT SHOULD BE PROVIDED OVER AT LEAST 6 m^2 AND SHOULD EXTEND TO AT LEAST HALF THE DEPTH OF THE ROOM FROM THE MAIN WINDOW.

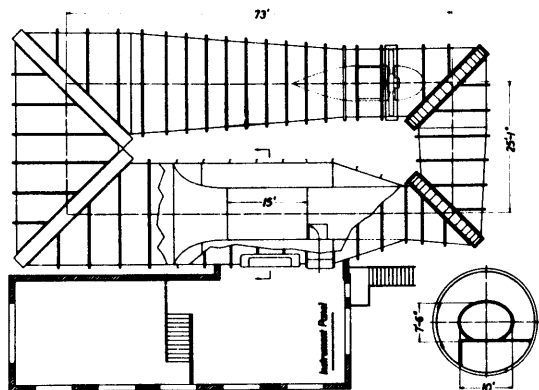
KITCHENS: A DAYLIGHT FACTOR OF NOT LESS THAN 2 PERCENT SHOULD BE PROVIDED OVER NOT LESS THAN 5 m^2 OR OVER 50 PERCENT OF THE TOTAL FLOOR AREA.

LYNES, J. A., PRINCIPLES OF NATURAL LIGHTING (LONDON: APPLIED SCIENCE PUBLISHERS LTD., 1968), p. 186.

APPENDIX E WIND TUNNEL STUDIES: INTERIOR AIR FLOW

Appendix E

Interior air flow caused by positive and negative pressure areas on the face of the building is analyzed in MIT's Wright Brothers Memorial Wind Tunnel. The closed-return variable density wind tunnel has a 15 foot long test section with minor and major axes of $7\frac{1}{2}'$ by $10'$ following an elliptical cross section.



The wind tunnel mechanically generates a laminar air flow which passes over a set of parabolic spires and a matrix of wooden blocks which simulate ground roughness. These spires and blocks impede the laminar flow, creating turbulence. Their dimensions and spacing can be varied to allow the modelling of different boundary layers such as lakes, oceans, or cities. In this particular

study, the boundary layer assumes city texture upstream of the building. The model to be analyzed is placed in an open area of the tunnel, downstream of the turbulence-generating system.

Instantaneous velocity and turbulence intensity are measured by a "hot wire," a constant temperature sensor. The "hot wire" consists of two prongs connected with a current-carrying wire. The cooling effect that the wind has on the wire is measured by the amount of current necessary to maintain the wire's constant temperature. The current passes through a resistance and is displayed as electrical potential or voltage on a cathode ray tube. An integrator circuit averages the instantaneous voltages over six seconds and records the average potential on a digital voltmeter. An analog voltmeter measures the turbulence intensity, the root mean square standard deviation of the integrated velocity.

Wind speed and turbulence intensity vary with altitude. Wind tunnel air flow velocity and turbulence are measured at 26", 18", 6", 4", 2" and 1" above the floor. With $1/16" = 1'-0$, these

elevations correspond to 416', 288', 96', 64', 32', and 16' above the surface of the earth.

The scale of the tested model is $1/2" = 1'-0$. This is not in scale with the wind tunnel air flow which assumes $1/16" = 1'-0$. As such, the modelled typical two level unit is 12" in height as opposed to $1\ 1/2"$, in scale with the wind tunnel.

This means the velocity gradient over the face of the modelled unit increases to 42% of free wind speed. The velocity gradient over the face of one unit properly scaled increases to only 8.33% of the free wind speed, $1/5$ of that modelled. The tested model is still within the parabolic segment of increasing velocity with increasing height. It is below the constant winds aloft speed.

The oversized model is also within the parabolic segment of increasing turbulence to height. At higher elevations, the turbulence begins to fall back to zero as free-field conditions exist above the earth boundary layer. The difference in turbulence between the top of the unit and the base is greater in the wind tunnel study than in the natural environment.

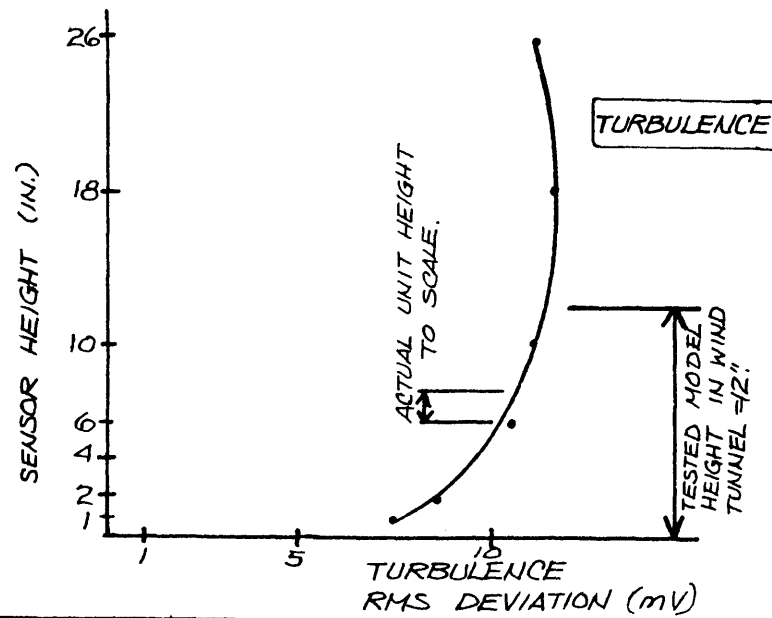
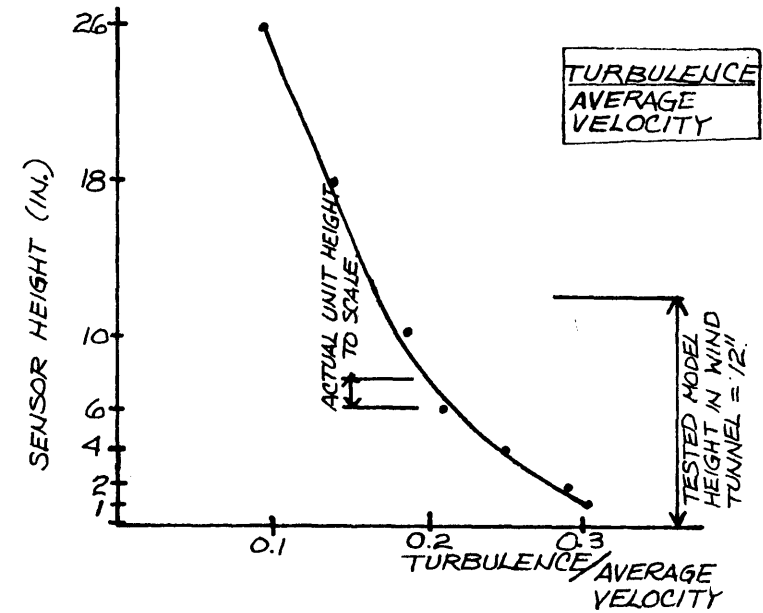
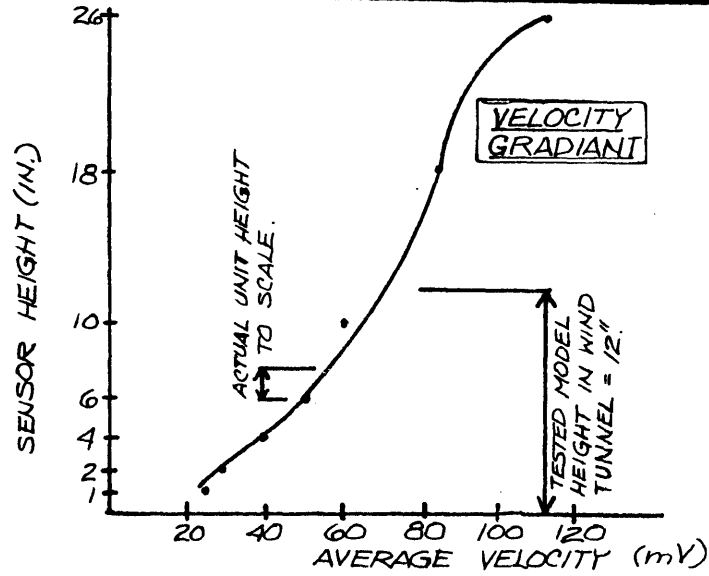
The chart and graphs on the following pages

show the velocity gradient and change in turbulence over the face of the unit as tested in the wind tunnel and the corresponding velocity gradient and turbulence that would occur if the model were in scale with the wind tunnel.

APPENDIX E

(INCHES) HEIGHT OF SENSOR	(FEET) MODELLED HEIGHT	(mV) AVERAGE VELOCITY	(mV) STANDARD RMS DEVIATION	VELOCITY VELOCITY @ 26"	DEVIATION DEVIATION @ 26"	DEVIATION VELOCITY
26"	416'	111.5 mV	11.0 mV	1.0	1.0	0.099
18"	288'	84.0 mV	11. mV	0.75	1.05	0.137
10"	160'	60.0 mV	11.0 mV	0.54	1.0	0.18
6"	96'	50.0 mV	10.5 mV	0.45	0.95	0.21
4"	64'	40.0 mV	10.0 mV	0.36	0.90	0.25
2"	32'	29.0 mV	8.5 mV	0.26	0.77	0.29
1"	16'	25.0 mV	7.5 mV	0.22	0.68	0.30

APPENDIX E



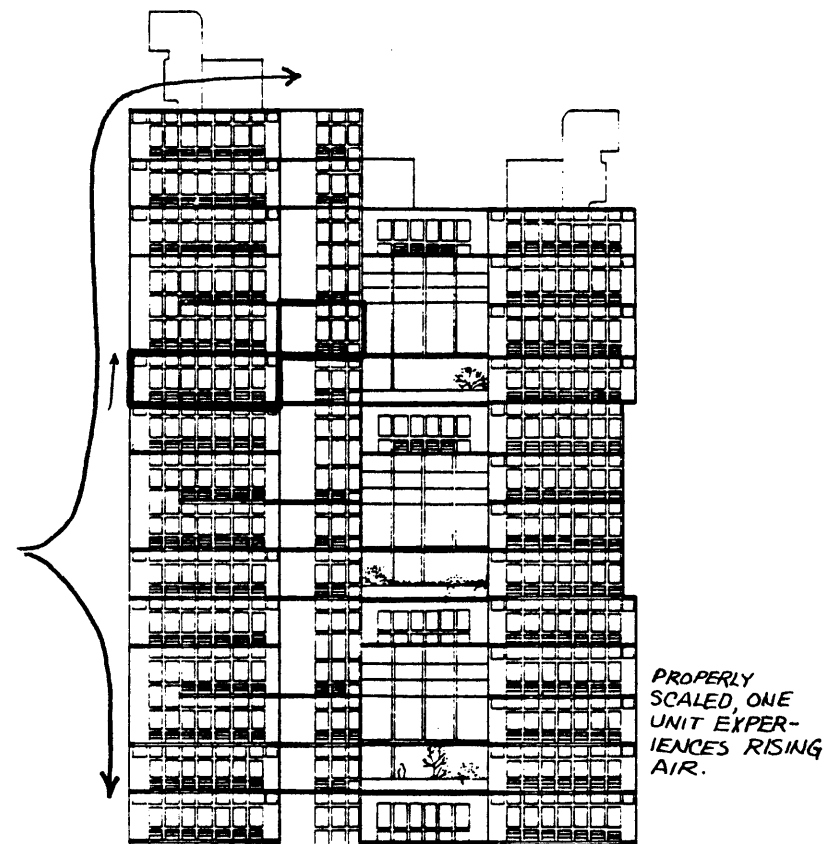
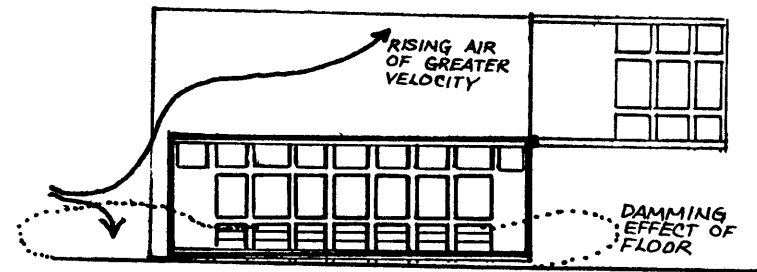
Such disparities do not lessen the validity of the qualitative test results if the inlet openings occur in the same vertical plane.

In the model study, part of the air sweeps up the face of the building and a portion drops to the base. The rising air is of higher velocity than that dropping. Air at the base may have a greater chance to enter the unit due to slower wind speeds and the damming effect of the floor.

In a properly scaled study of the entire building, one unit would experience either rising or falling air flow, not both.

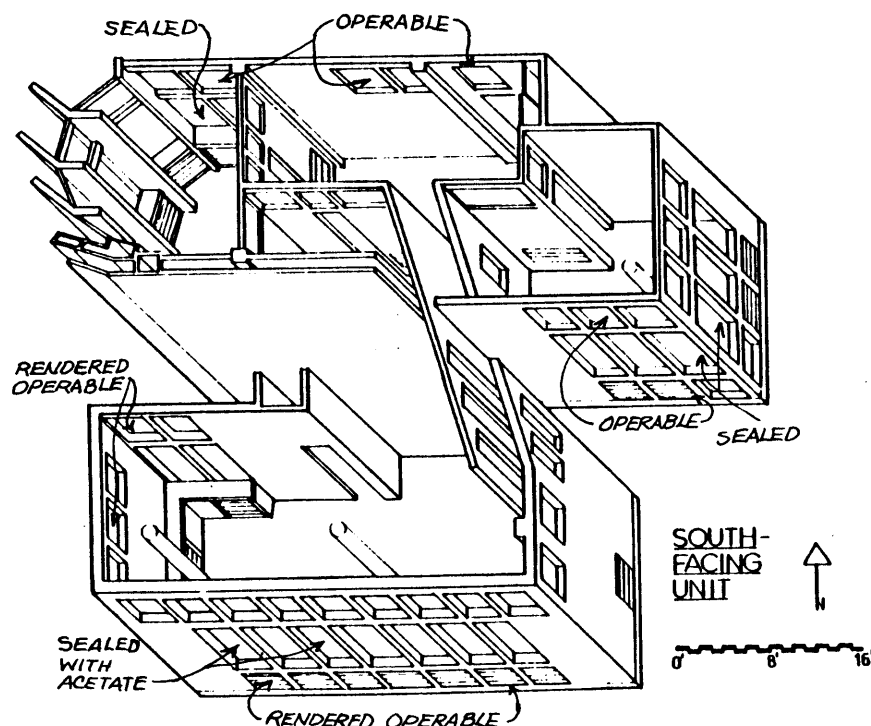
With the base louvers opened and the transom windows sealed, or vice versa, the air enters at one vertical plane. The effect of the velocity gradient and the difference in air flow patterns over the vertical height of the unit are of little consequence.

The velocity of air flow within the wind tunnel is 7 to 8 feet per second. This is considerably less than average wind speed out-of-doors. It is assumed that air flow patterns do not change significantly with increased speed. Tests conducted at Texas A and M College system verify the validity of this assumption. (Smith, The



Feasibility of Using Models for Predetermining Natural Ventilation).

An oil base smoke stream visually traces air flow in and about objects placed in the wind tunnel. The smoke spray wand is manually controlled. This permits the model to be filled with smoke, and the pattern of draining to be observed.

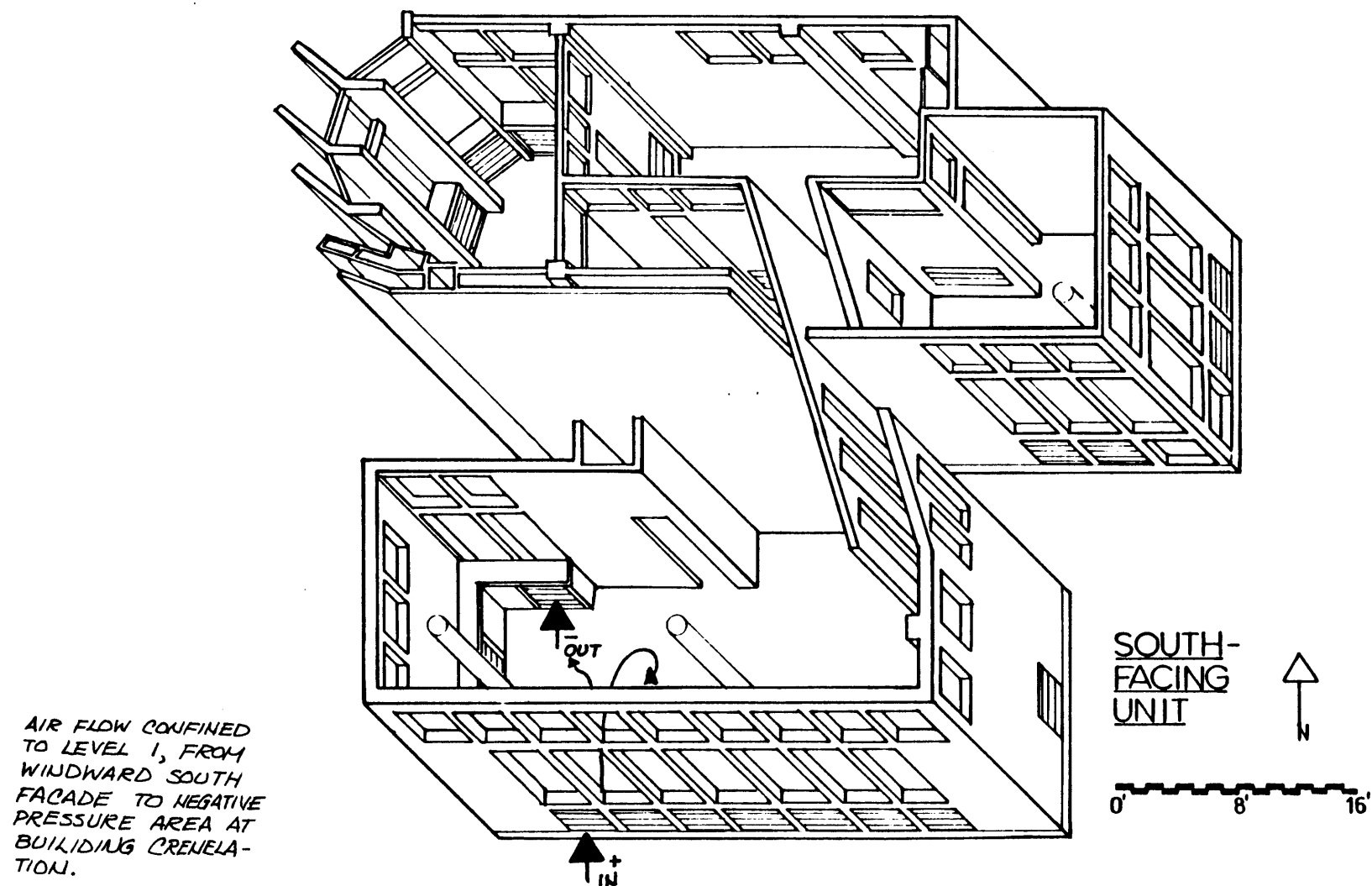


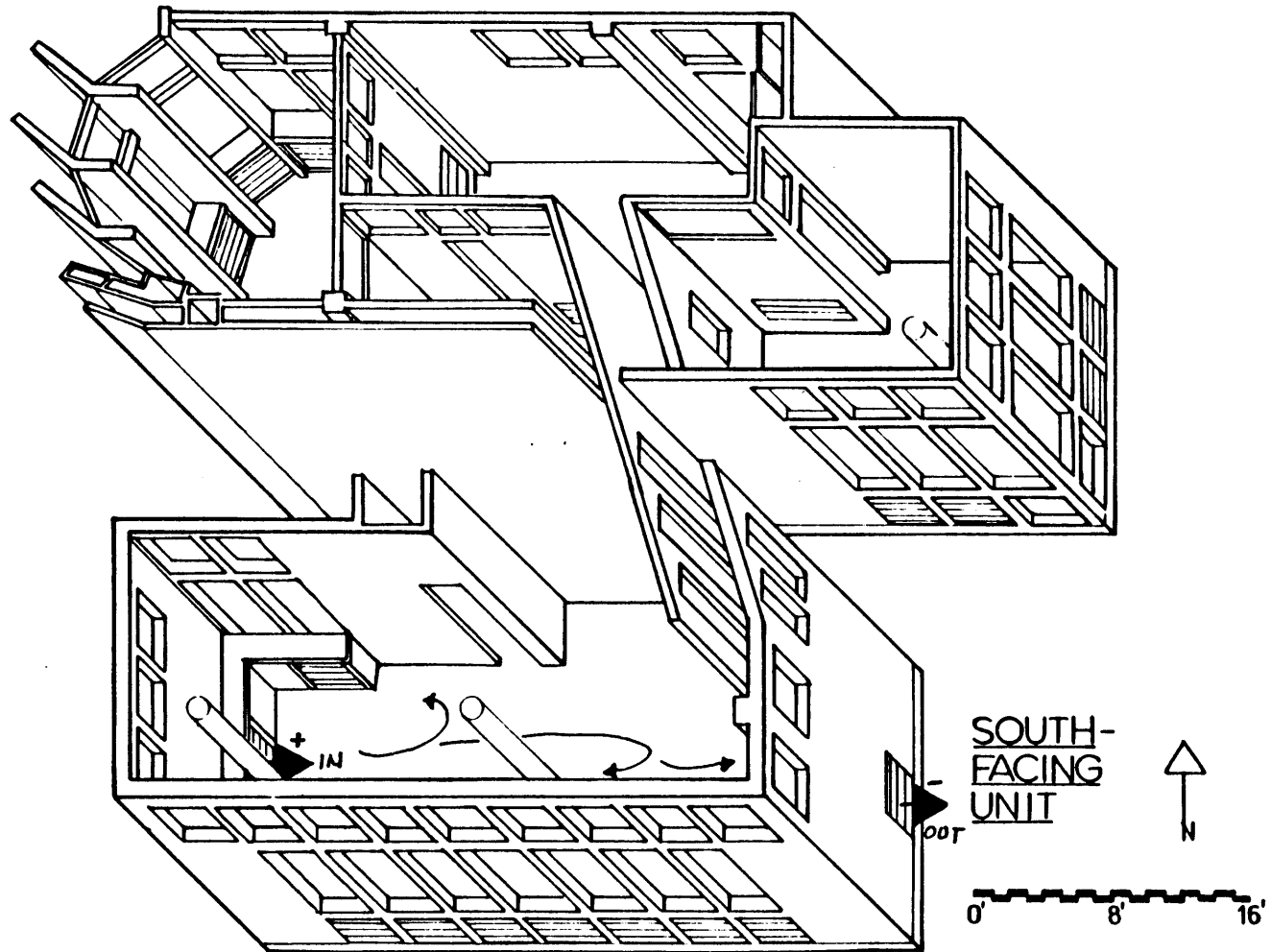
The $1/2'' = 1'-0$ scale model for light studies is rendered airtight for the study. Nonoperable windows are sealed with acetate; the operable clere-stories are taped with acetate for easy removal; and removable panels are applied to the exterior of the "ventilation boxes." The locations of air entry and exit are thereby controlled by removing and replacing various pieces of acetate and panels. A $2\ 1/2$ story facade built both above and below the tested unit better simulates wind behavior in and around a tall structure.

The southwest corner of the model is oriented to face the air flow, representative of the prevailing summer wind in Boston.

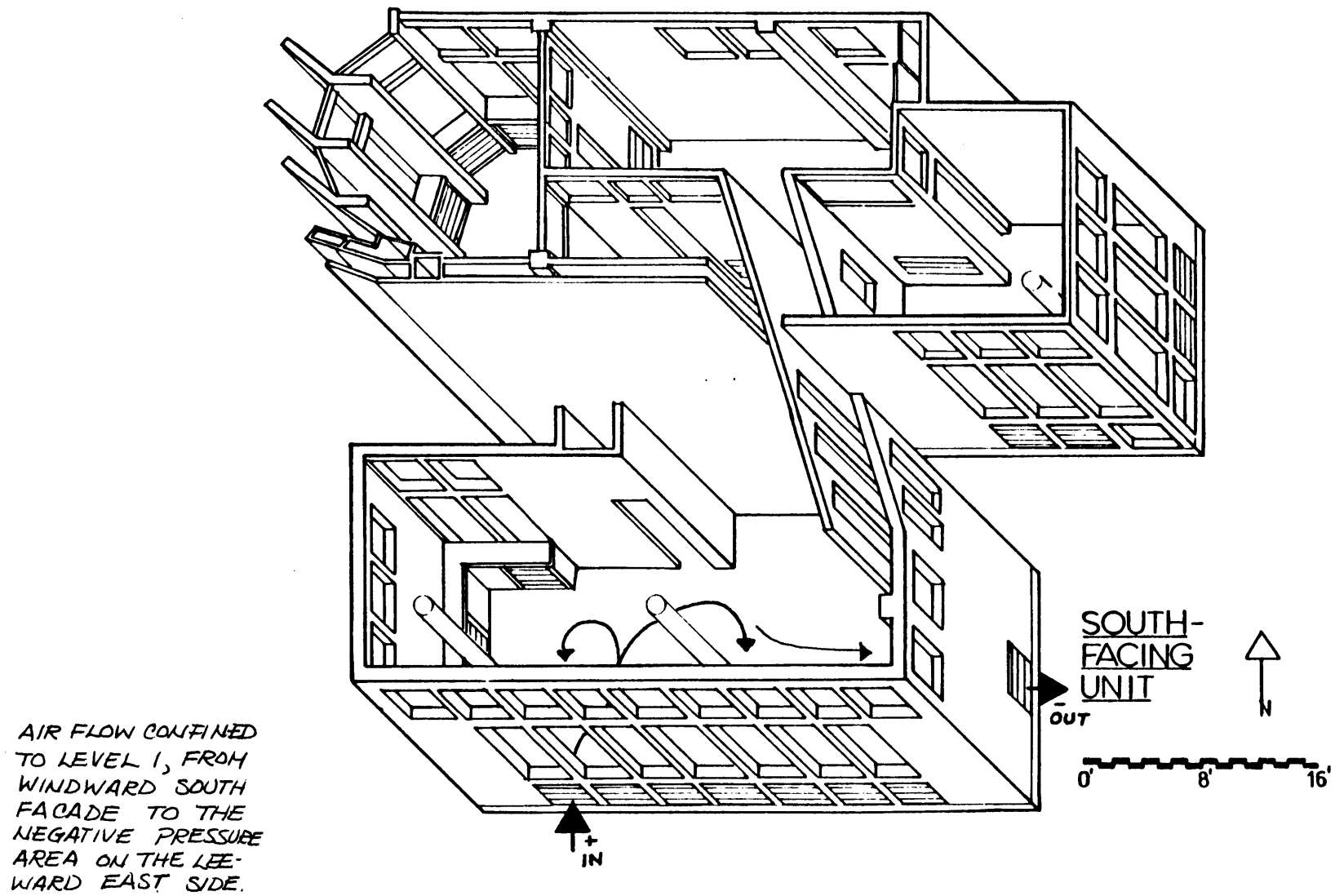
The following illustrations depict air flow patterns as observed in the wind tunnel. Arrows indicate open windows and louvers. The rest of the building is sealed to infiltration.

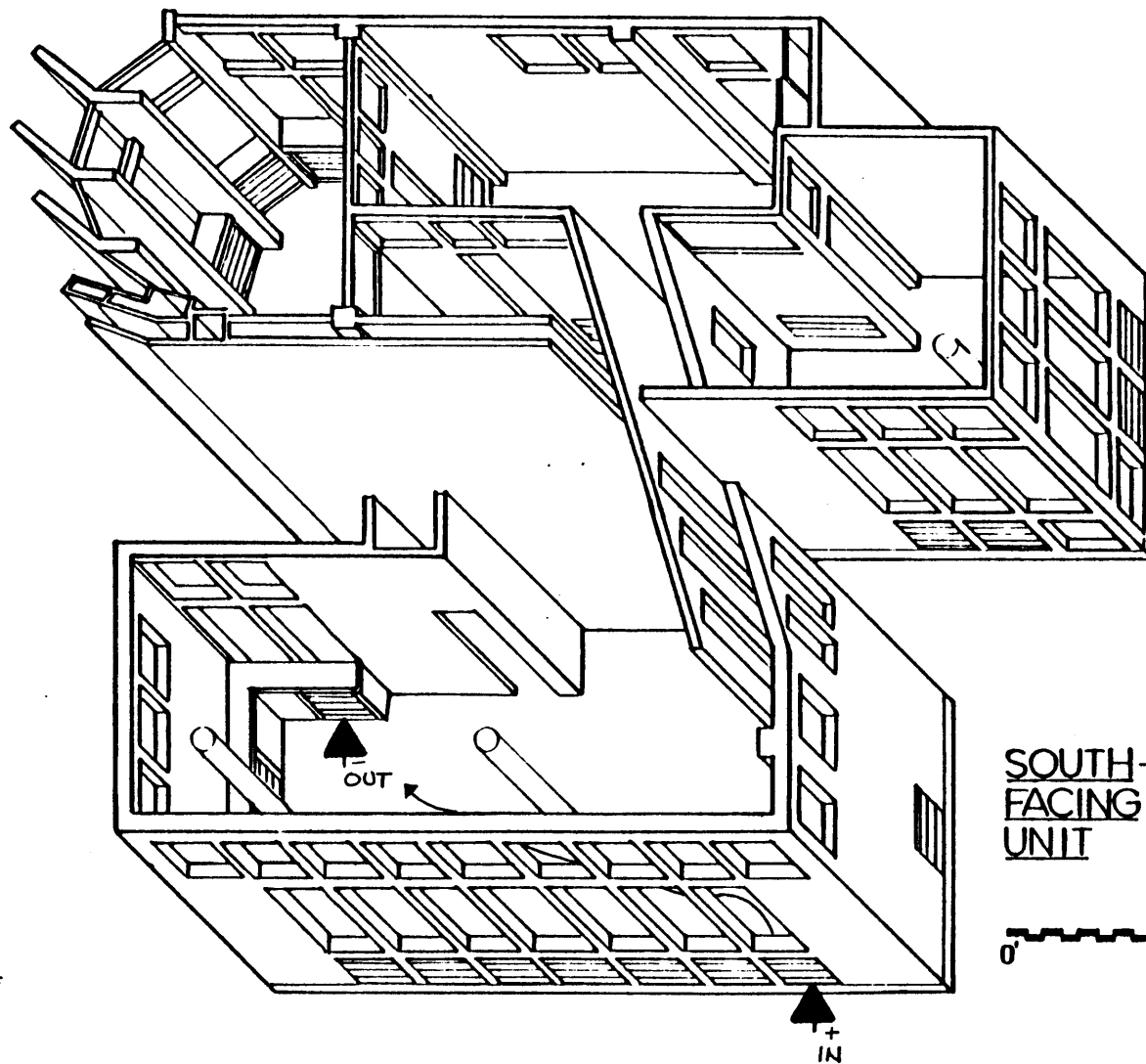
It is difficult to determine the vertical plane of air flow. But with properly angled jalousie louvers, this can be controlled by the inhabitant. The pattern of air flow in plane, and its distribution from level 1 to level 2 are of interest in these diagrams.





AIR FLOW CONFINED
TO LEVEL 1, FROM
WINDWARD WEST
FACADE TO NEGATIVE
PRESSURE AREA ON
EAST FACADE.



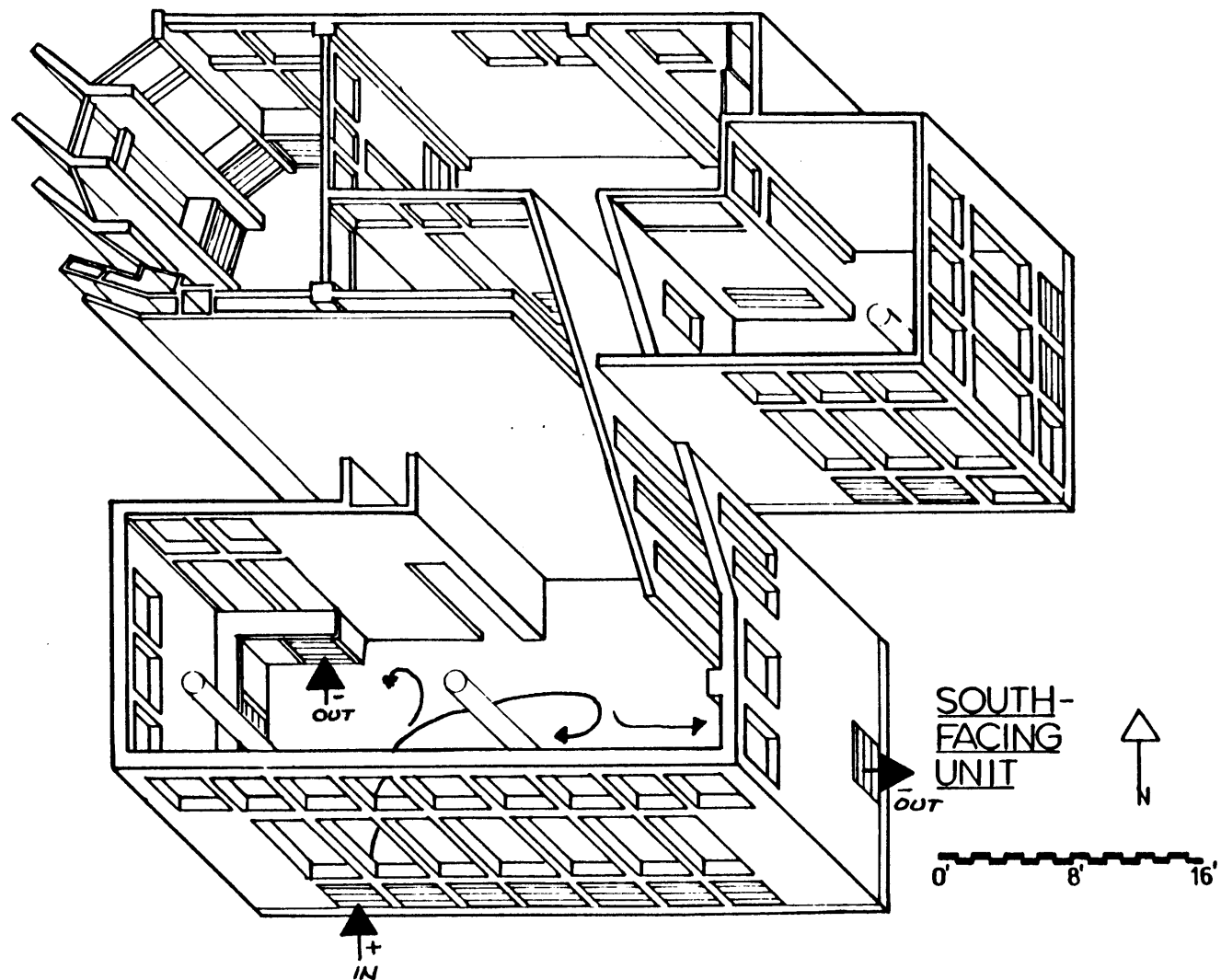


AIR FLOW DIAGONALLY
ACROSS LEVEL 1,
FROM WINDWARD
SOUTH FAÇADE TO
NEGATIVE PRESSURE
AREA AT BUILDING
CRENELATION

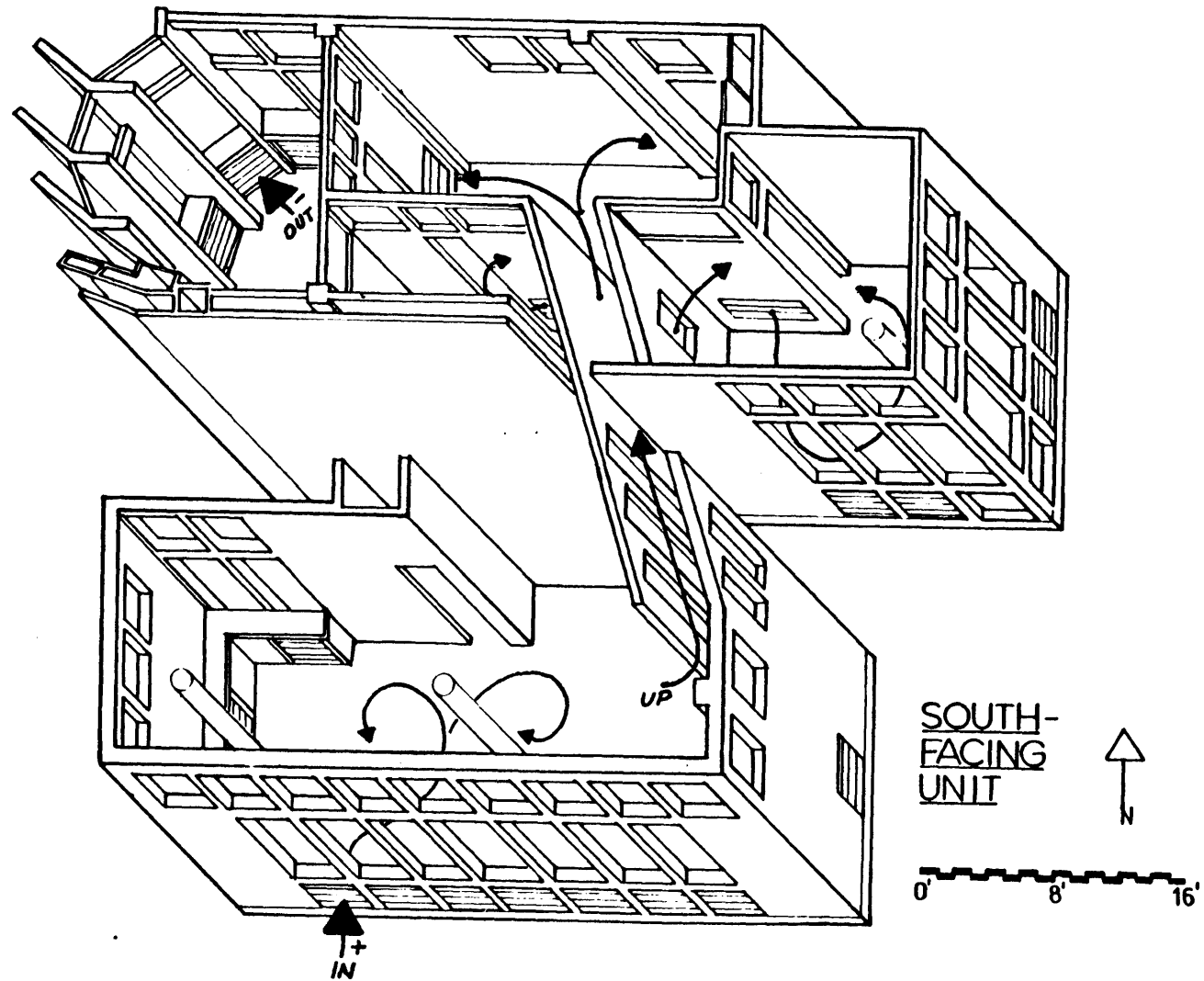
SOUTH-
FACING
UNIT

0' 8' 16'

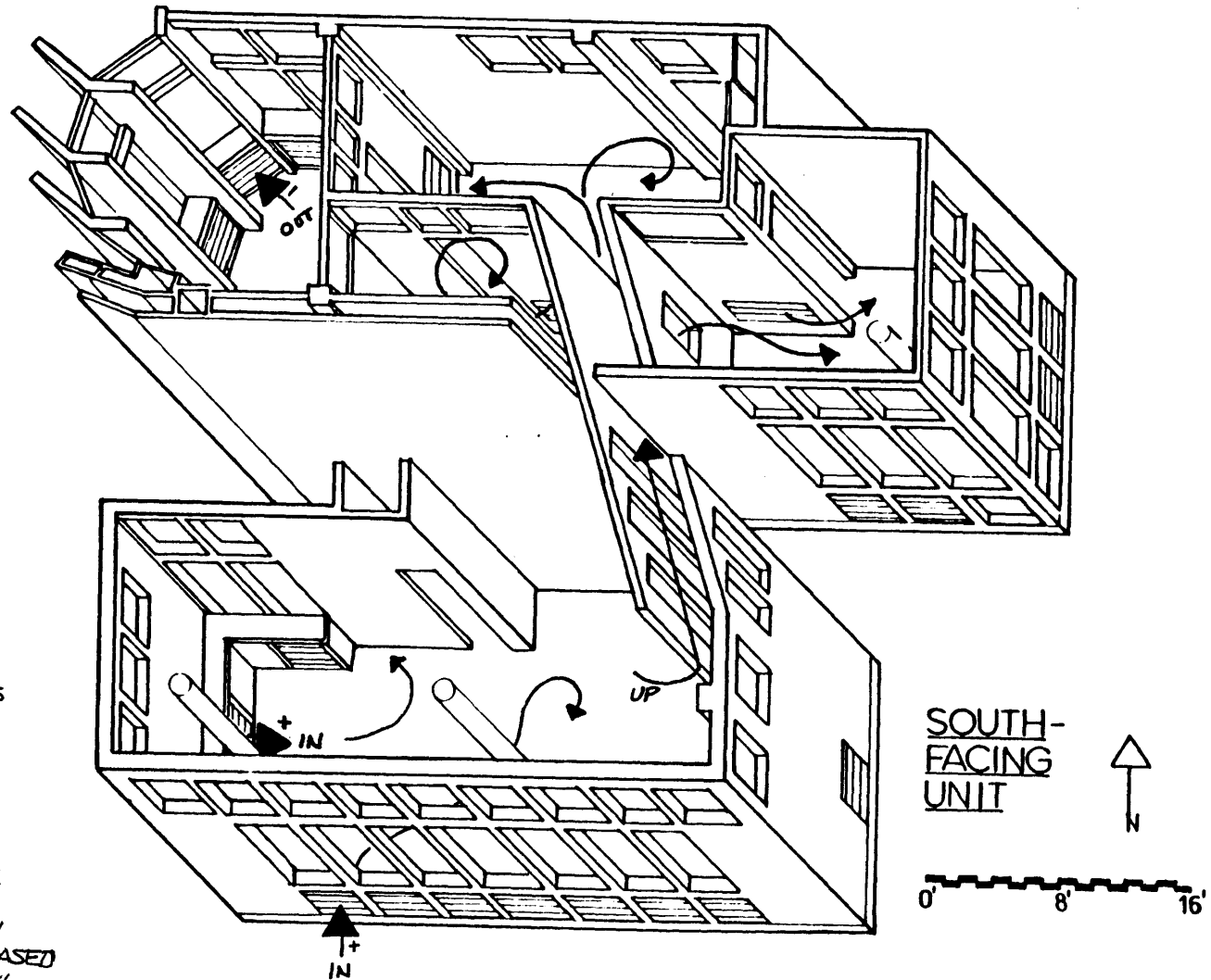
ONE INLET, TWO
OUTLETS OPEN;
AIR DOES NOT
SHORT CIRCUIT
OUT CLOSER OUTLET
BUT IS DISTRIBUTED
THROUGHOUT LEVEL
1; DRAINS FROM
NORTH AND EAST.
GREATER AREA OF
OUTLET THAN INLET
MEANS INCREASED
SPEED OF AIR FLOW.



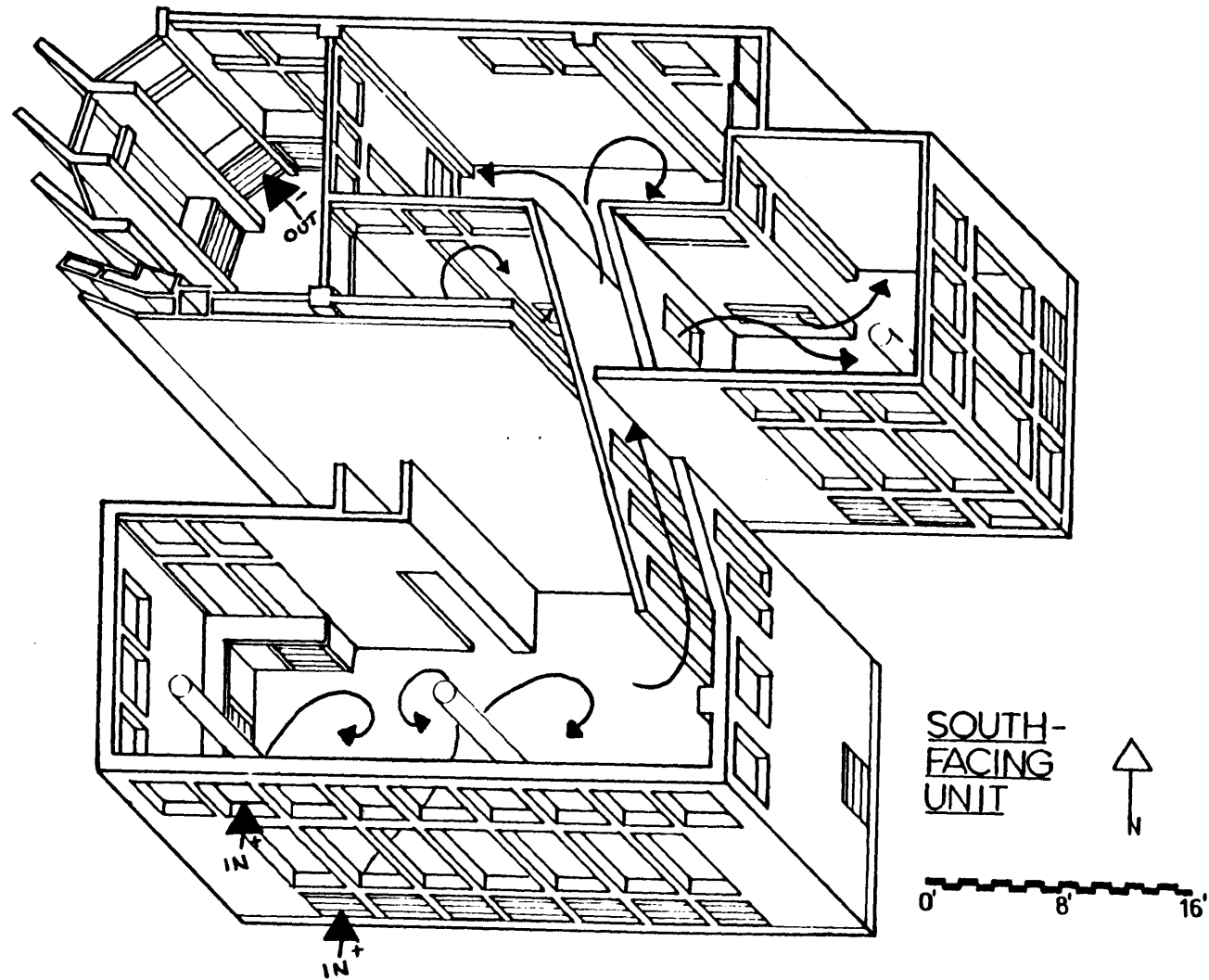
AIR FLOW FROM WIND-
WARD SOUTH FACE
LEVEL 1, UP STAIR
SHAFT, THROUGHOUT
LEVEL 2, AND OUT
OPENING IN NEGATIVE
PRESSURE ZONE
CREATED BY VERTICAL
FINS.



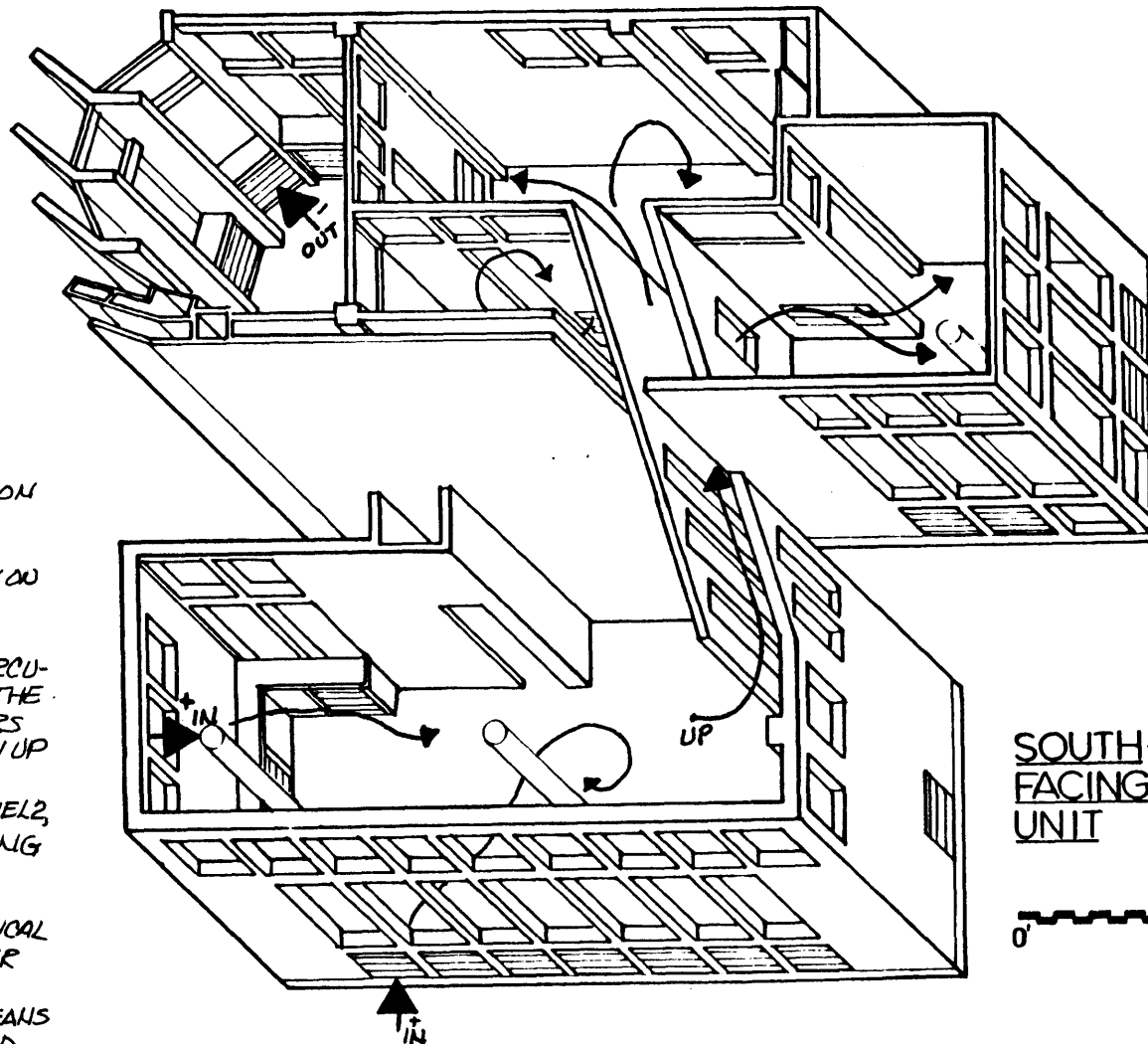
AIR FLOW FROM WIND-
WARD SOUTH FACE
AND WEST FACE;
AIR DOES NOT CIR-
CULATE BETWEEN
THE TWO, BUT ENTERS
BOTH; AIR FLOW
UP STAIR SHAFT,
THROUGHOUT LEVEL,
AND OUT OPENING
IN NEGATIVE
PRESSURE ZONE
CREATED BY VERTICAL
FINS. GREATER
AREA OF INLET THAN
OUTLET MEANS DECREASED
SPEED OF AIR FLOW.



AIR FLOW FROM
 "VENTILATION BOX"
 AS WELL AS FROM
 CIERESTORY ON
 LEVEL 1; AIR DOES
 NOT CIRCULATE
 BETWEEN THE TWO,
 BUT ENTERS BOTH;
 AIR FLOW UP
 STAIR SHAFT,
 THROUGHOUT LEVEL 2,
 AND OUT OPENING
 IN NEGATIVE
 PRESSURE ZONE
 CREATED BY
 VERTICAL FINIS.
 GREATER AREA OF
 INLET THAN
 OUTLET MEANS
 DECREASED SPEED
 OF AIR FLOW.



AIR FLOW IN FROM "VENTILATION BOX" ON WINDWARD SOUTH FACE AS WELL AS FROM CLERESTORY ON WINDWARD WEST FACE ON LEVEL 1; AIR DOES NOT CIRCULATE BETWEEN THE TWO, BUT ENTERS BOTH. AIR FLOW UP STAIR SHAFT, THROUGHOUT LEVEL 2, AND OUT OPENING IN NEGATIVE PRESSURE ZONE CREATED BY VERTICAL FINS. GREATER AREA OF INLET THAN OUTLET MEANS DECREASED SPEED OF AIR FLOW.

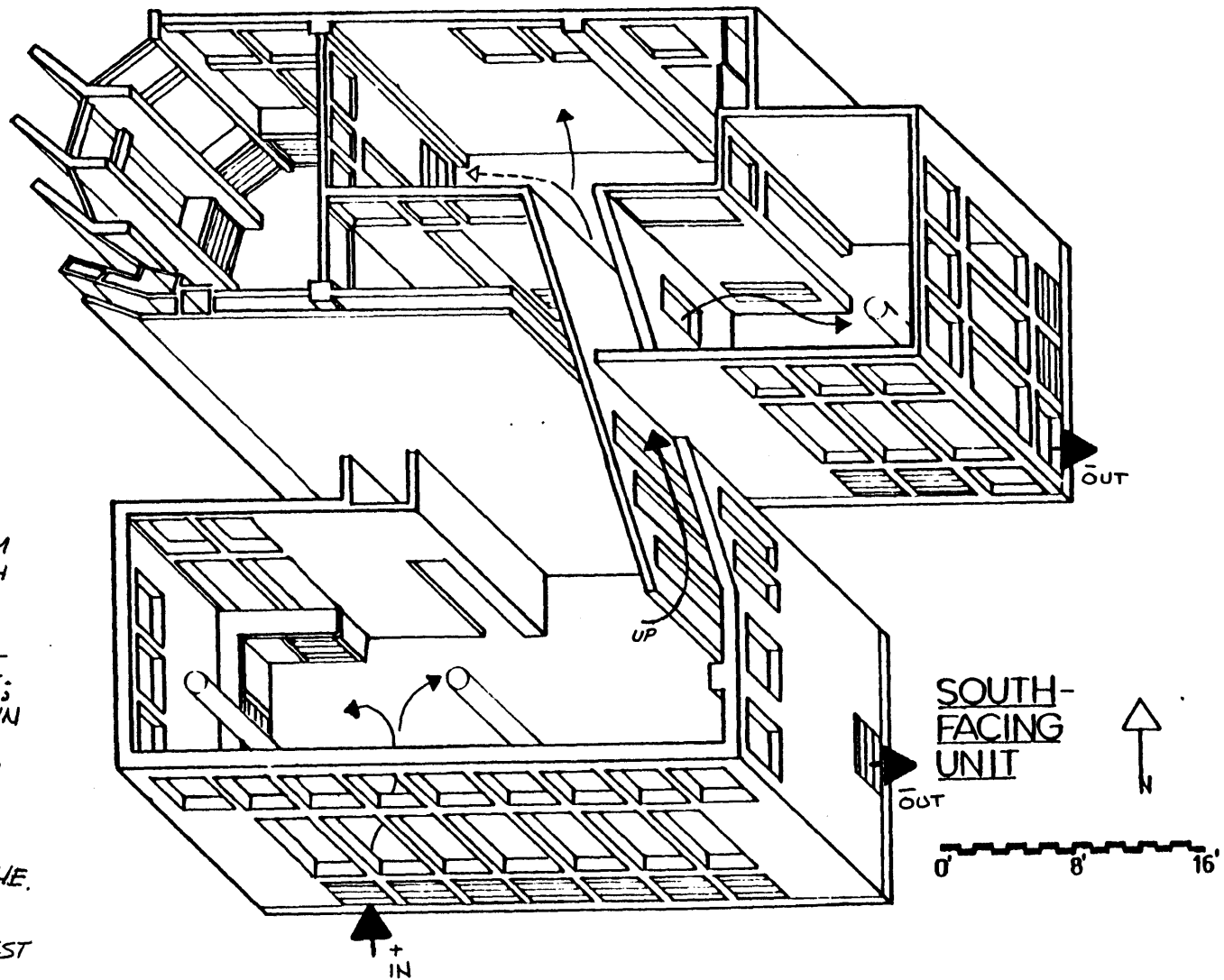


SOUTH-
FACING
UNIT



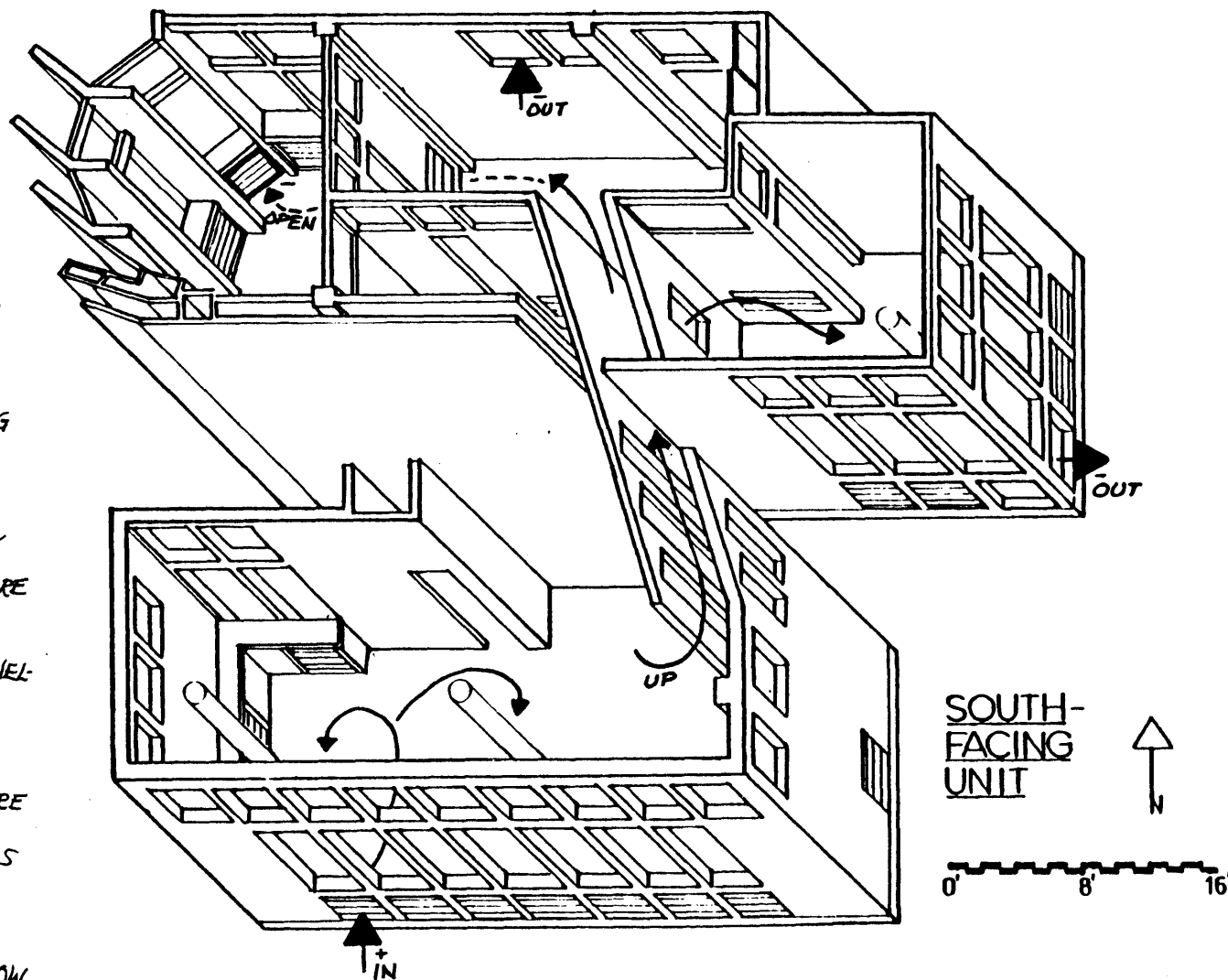
0' 8' 16'

AIR FLOW IN FROM
WINDWARD SOUTH
FACE, ACROSS
LEVEL 1, AND OUT
LEVEL 1, AND OUT
OPENING TO LEE-
WARD EAST SIDE;
SOME AIR DRAWN
UP STAIR SHAFT,
THROUGH ROOM
TO RIGHT AND
OUT OPENING
IN NEGATIVE
PRESSURE ZONE.
NOT MUCH AIR
DISTRIBUTION
THROUGHOUT REST
OF LEVEL 2.

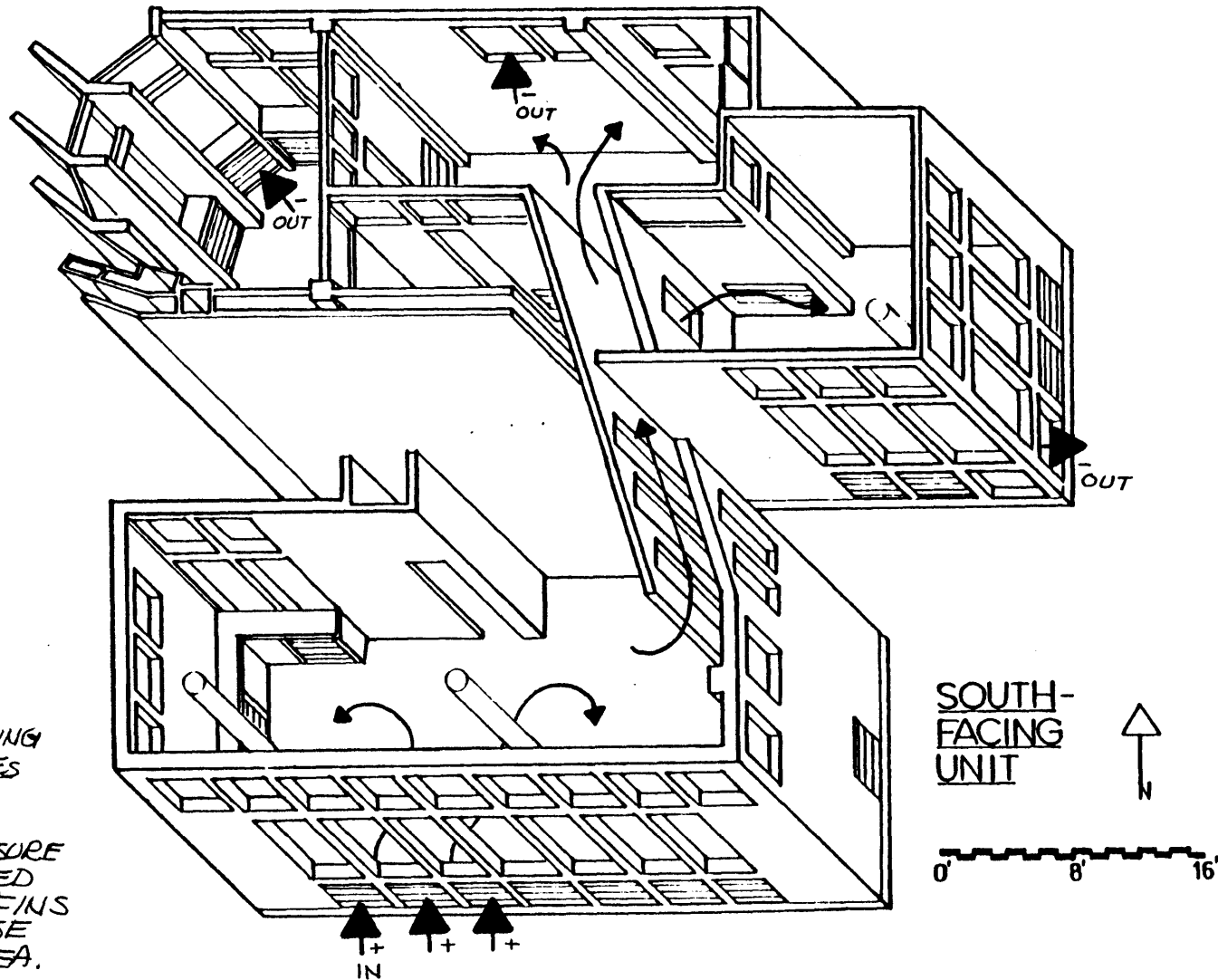


AIR FLOW IN FROM WINDWARD SOUTH FACE, UP STAIR SHAFT, THROUGH ROOM TO RIGHT AND OUT OPENING IN NEGATIVE PRESSURE ZONE TO EAST. SOME AIR DRAWN TO OPEN CLOREESTORY AND OUT TO NEGATIVE PRESSURE ZONE CREATED BY FIRE STAIR BUILDING CRENELATION.

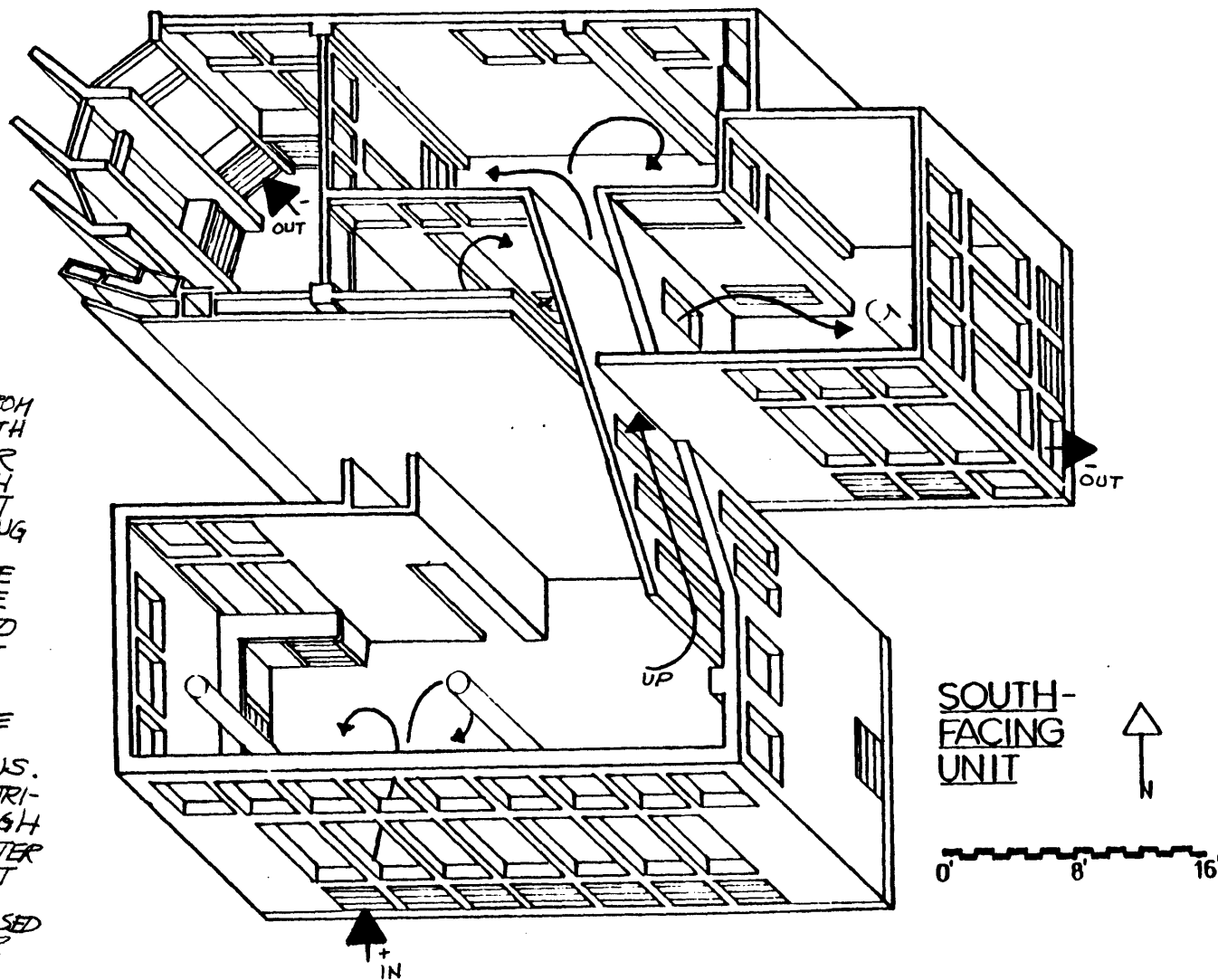
AIR DOES NOT FLOW OUT OF OPENING TO NEGATIVE PRESSURE ZONE CREATED BY VERTICAL FINS GREATER AREA OF INLET THAN OUTLET MEANS DECREASED SPEED OF AIR FLOW.



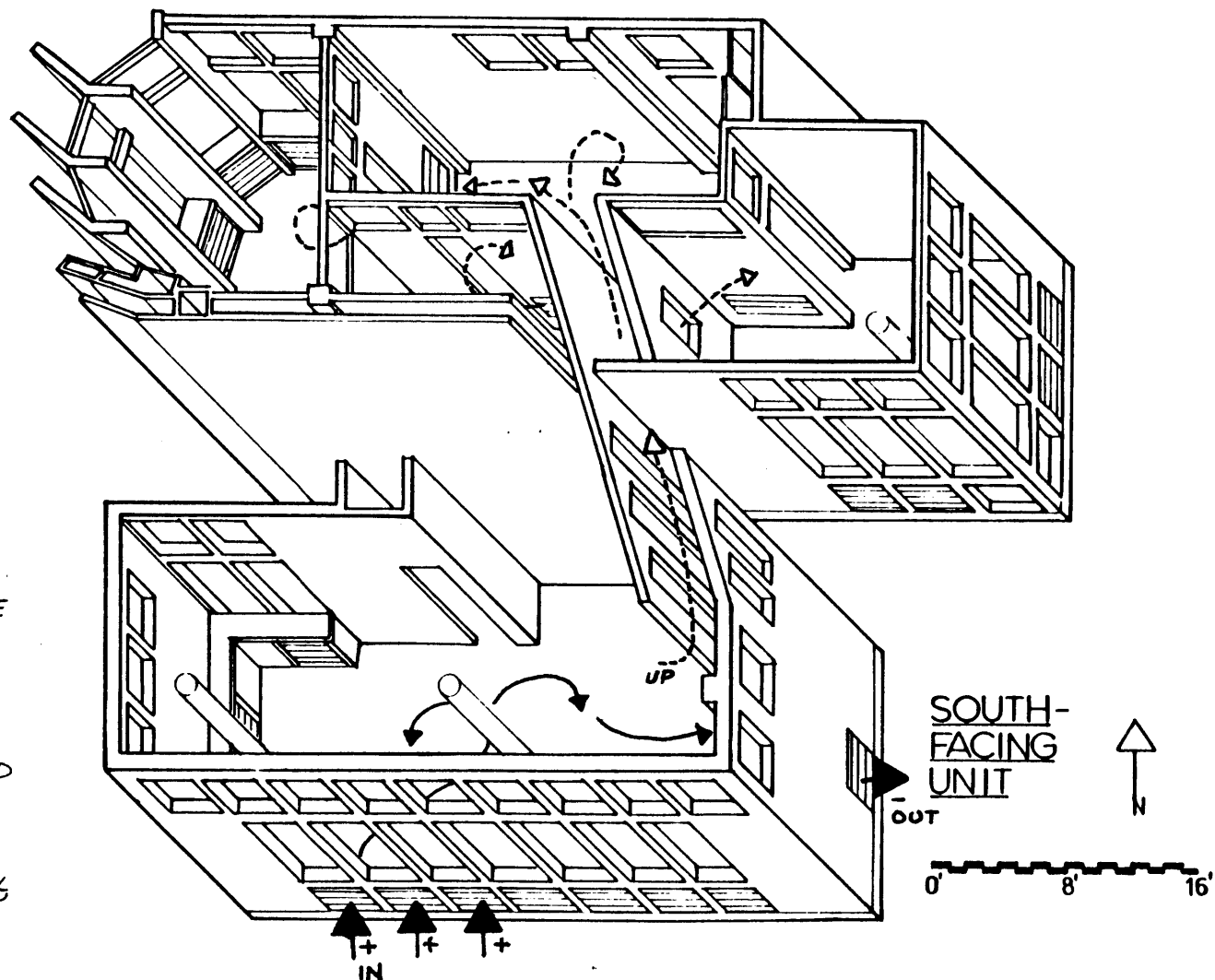
(REFER TO PRECEDING PAGE) AIR DOES FLOW OUT OF OPENING TO NEGATIVE PRESSURE ZONE CREATED BY VERTICAL FINS WITH INCREASE IN INLET AREA.



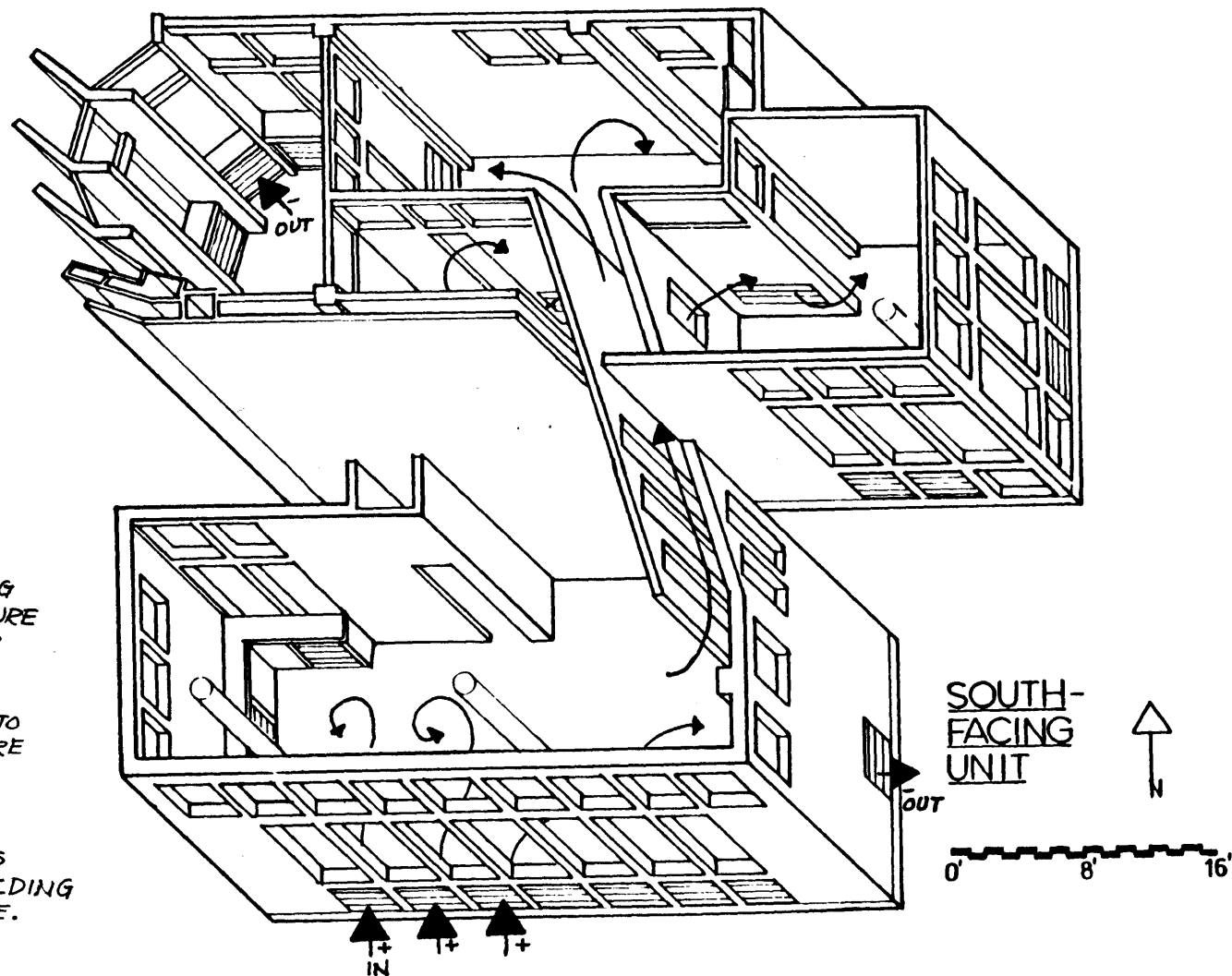
AIR FLOW IN FROM
WINDWARD SOUTH
FACE, UP STAIR
SHAFT, THROUGH
ROOM TO RIGHT
AND OUT OPENING
IN NEGATIVE
PRESSURE ZONE
TO EAST; SOME
AIR DRAWN TO
ROOM TO WEST
AND OUT TO
NEGATIVE
PRESSURE ZONE
CREATED BY
VERTICAL FIN.
GOOD AIR DISTRI-
BUTION THROUGH
LEVEL II. GREATER
AREA OF OUTLET
THAN INLET
MEANS DECREASED
SPEED OF AIR
FLOW.



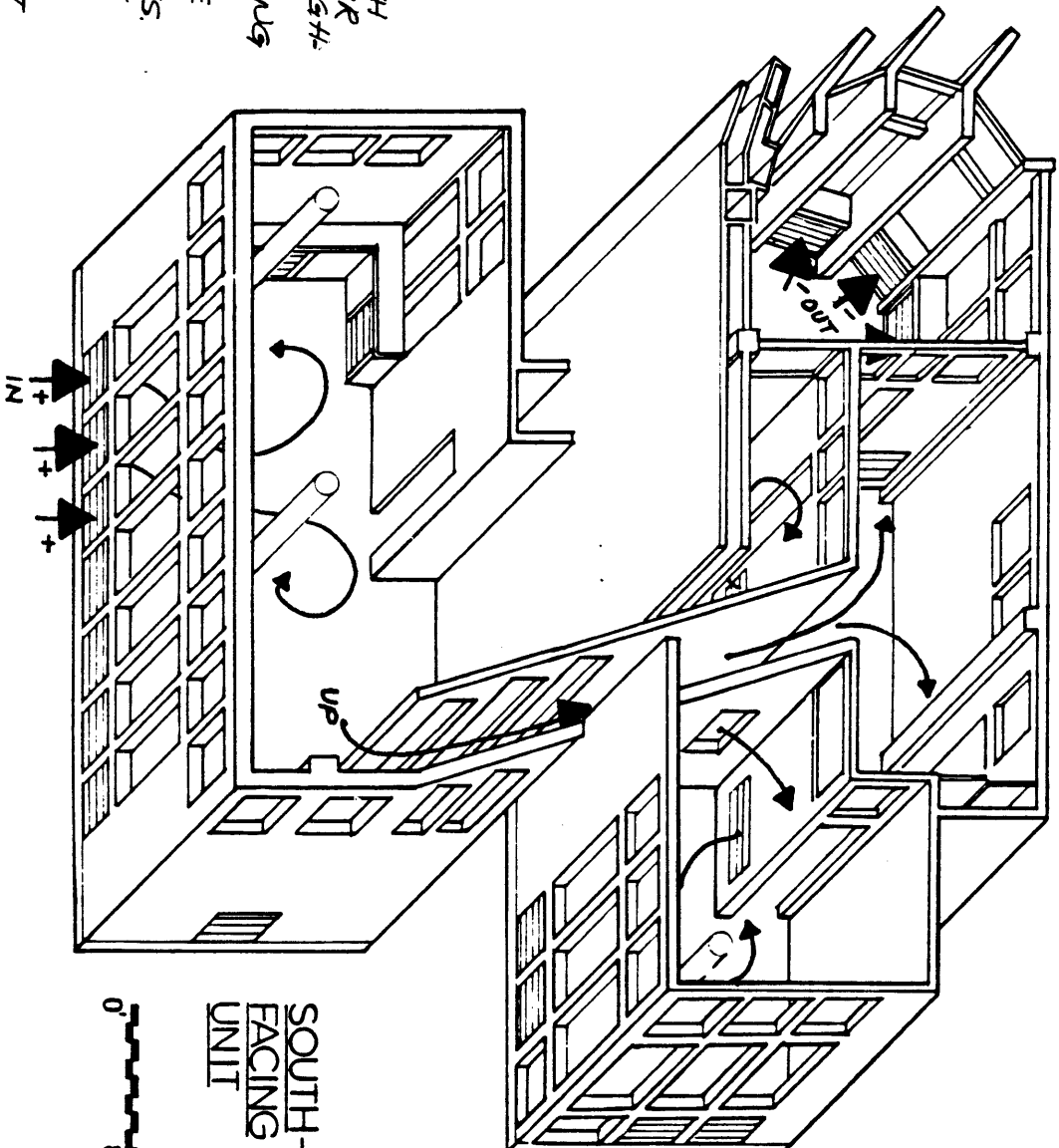
AIR FLOW IN FROM
WINDWARD SOUTH
FACE, ACROSS
LEVEL 1, AND OUT
OPENING IN NEGATIVE
PRESSURE ZONE
TO LEEWARD EAST
SIDE; GREATER
AREA OF INLET
THAN OUTLET
MEANS DECREASED
SPEED OF AIR
FLOW; DAMMING
EFFECT OCCURS
ALONG EAST WALL,
PILES UP THE
STAIR SHAFT TO
LEVEL 2; DOES
NOT CIRCULATE.



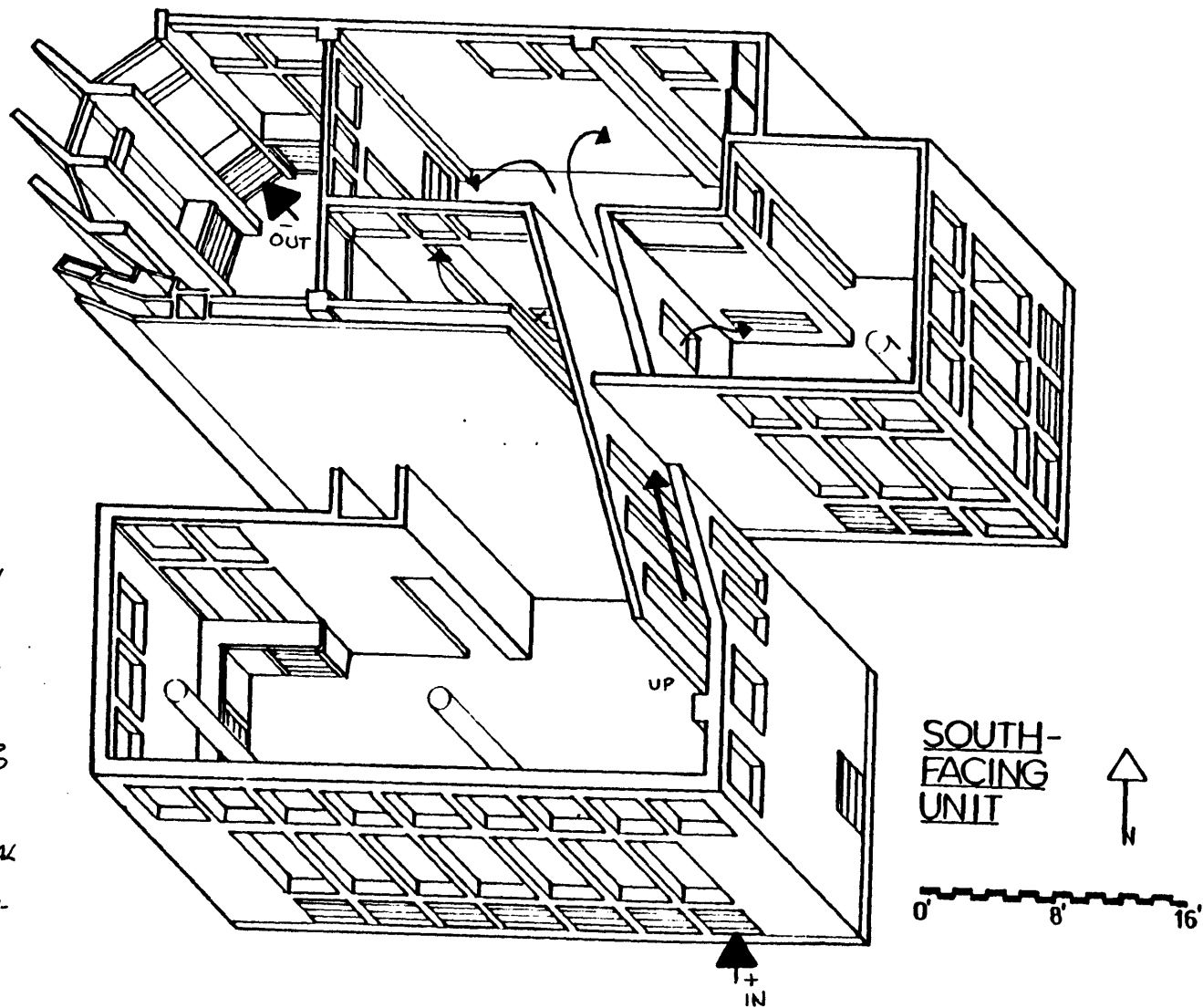
AIR FLOW FROM
WINDWARD SOUTH
FACE, THROUGHOUT
LEVEL 1, OUT OPENING
IN NEGATIVE PRESSURE
ZONE TO EAST; AIR
DRAWN UP STAIR
SHAFT, THROUGH
LEVEL 2, AND OUT TO
NEGATIVE PRESSURE
ZONE CREATED BY
VERTICAL FINIS.
THIS RELIEVES
PIUNG EFFECT AS
NOTED ON PRECEDING
PAGE.

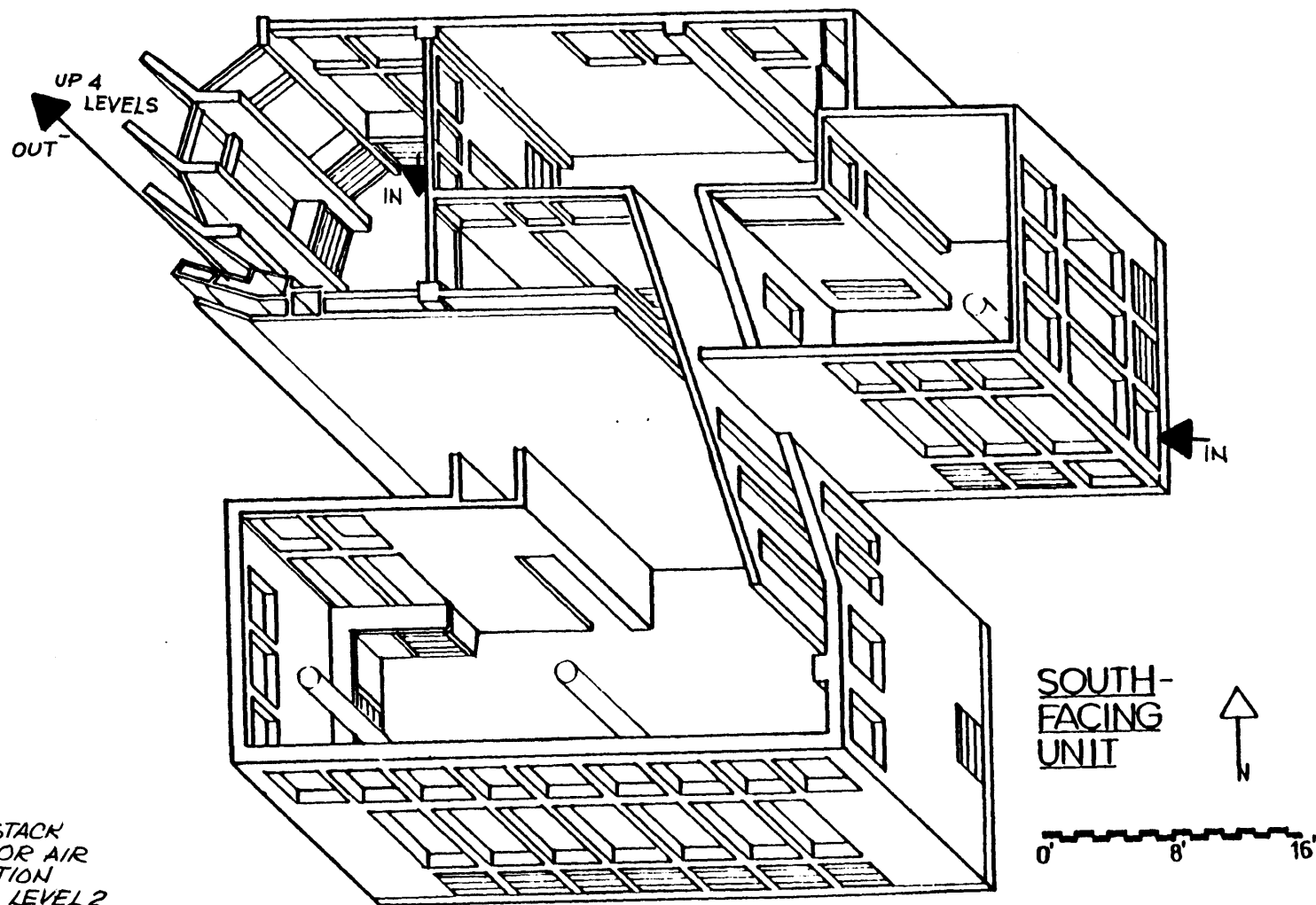


FLOW IN FROM
 SWIAED SOUTH
 SIDE, UP STAIR
 9FT, THROUGH
 LEVEL 2
 D OUT OPENING
 NEGATIVE
 SSURE ZONE
 ATED BY
 ETICAL #115.
 4 TO RIGHT
 VIES SOME
 COLATION
 SPITE OF
 AIR OUTLET
 E.



FOR AIR DISTRIBUTION
THROUGH LEVEL 2,
OPEN VENT AT
STAIR BASE ON
WINDWARD SOUTH
SIDE; AIR FLOWS
UP STAIRSHAFT,
THROUGH OUT LEVEL 2,
AND OUT OPENING
TO NEGATIVE
PRESSURE ZONE
CREATED BY VERTICAL
FINS.
NOT MUCH AIR CIRCULATION
THROUGH
LEVEL 1.





USE OF STACK
EFFECT FOR AIR
CIRCULATION
THROUGH LEVEL 2.
WITH NO INLET
OPENED IN LEVEL 1,
NO AIR FLOW HERE.

Overall, this study demonstrates the flexibility of the natural ventilation system and demonstrates the success of the flow-through organization.

Natural ventilation can occur through level 1, independent of level 2, and through level 2, independent of level 1. Air can enter a positive pressure inlet at level 1, funnel up the stair shaft, distribute evenly throughout level 2, and exit from this upper level to an area of relative negative pressure.

Multiple inlet openings and multiple outlet openings do not seem to short circuit each other as might be expected. With air entering the windward face at level 1, an open outlet at this level does not prevent air from exiting an open outlet at level 2.

There are several potential limitations to the validity of the results of this investigation.

1) The most obvious limitation is the ever-present question of wind behavior in and around tall structures. Less than 1/4 of the building is modelled in plan. Building facades modelling 2 1/2 stories above and below the tested unit make for a model height of 6 stories, only 1/4 of the total building height. Wind patterns, as affected

by the entire building are undoubtedly significantly different. Also, the 5 added stories were removed due to their awkward arrangement in the wind tunnel. The elevation of the tested unit is then only 1/24 of the total building height. But no visible difference occurs with the removal of the 5 stories.

2) Although the spires and block grid simulate city boundary layer, the model is located below an average unit elevation. As formerly discussed, the model is at a scale of 1/2" = 1'0, somewhat large for the tunnel wind gradients and changes in turbulence with added height.

3) Subtle changes in building details or furniture placement may produce significant changes in air flow patterns. A minor change in window design can divert air flow from near the ceiling to near the floor for increased comfort. Such details are difficult to model, and their effects cannot be measured. This also implies that small errors in model construction can lessen the accuracy of the results. For example, if a deep frame at the window head causes air to rise, a disproportionately modelled frame would not create this effect.

4) The white lighting model is used for the

wind tunnel test. The light grey smoke, a visual indicator of air flow patterns, is difficult to read against the white model surface. A dark model, producing higher contrast with the smoke, would be more effective for reading and flow patterns.

In spite of these limitations inherent in the testing method, most of the observations seem intuitively correct. The investigation is considered valid for its qualitative information.

APPENDIX F

HOURLY INTERNAL HEAT GAINS:

	<u>BTU</u>
PEOPLE: 420 BTU/HOUR/PERSON x 3 PEOPLE x 12 HOURS	15,120
REFRIGERATOR: $2\frac{1}{2}$ KILOWATT/HOURS / DAY x 3,412 $\frac{\text{BTU}}{\text{KWH}}$	8,530
RADIO: 1 KILOWATT/HOUR / DAY x 3,412 $\frac{\text{BTU}}{\text{KWH}}$	3,412
LIGHTS: $\frac{5.5 \text{ KILOWATTS}}{1800 \text{ SQUARE FEET}} \times 1,400 \text{ SQUARE FEET} \times 3,412 \frac{\text{BTU}}{\text{KWH}} \times \frac{2}{3} \text{ (FOR DAY LIGHTING)}$	9,733
STOVE: 18,600 BTU/DAY $\frac{\text{FAMILY OF FOUR}}{\text{FOUR}} \times \frac{3}{4}$	13,950
EXTRA APPLIANCES: 1 KILOWATT/HOUR / DAY x 3,412 $\frac{\text{BTU}}{\text{KWH}}$	3,412

TOTAL: 54,157 $\frac{\text{BTU}}{\text{DAY}}$

ASSUME: 54,000 BTU/DAY

THE STACK, SIZED FOR A TYPICAL SOUTH-FACING UNIT, IS TO REMOVE HOURLY INTERNAL HEAT GAINS WITH A MINIMUM DIFFERENCE BETWEEN INDOOR AND OUTDOOR TEMPERATURES.

APPENDIX E

GIVEN THE AMOUNT OF HEAT TO BE REMOVED FROM A BUILDING, AND THE TEMPERATURE DIFFERENCE BETWEEN INDOORS AND OUT, THE RATE OF VENTILATION AIR FLOW TO MAINTAIN THIS TEMPERATURE DIFFERENCE IS FOUND:

$$Q = \frac{H}{60 C_p \rho (t_i - t_o)} \quad \text{WHERE:}$$

Q = AIR REMOVED, CUBIC FEET PER MINUTE;

H = HEAT REMOVED, BTU PER HOUR;

C_p = SPECIFIC HEAT OF AIR AT CONSTANT PRESSURE; (0.245 BTU PER POUND PER °F)

ρ = DENSITY OF STANDARD AIR; (0.075 POUNDS PER CUBIC FOOT)

$t_i - t_o$ = AVERAGE INDOOR TO OUTDOOR TEMPERATURE DIFFERENCE, °F.

TO REMOVE HOURLY HEAT GAINS WHEN INTERIOR TEMPERATURE IS 5° GREATER THAN EXTERIOR:

$$H = \frac{54,000 \frac{\text{BTU}}{\text{DAY}}}{24 \frac{\text{HOURS}}{\text{DAY}}} = 2,257 \text{ BTU/HOUR}$$

$$t_i - t_o = 5^\circ \text{ F}$$

$$Q = \frac{2,257}{60 (0.245) (0.075) (5^\circ)}$$

$$Q = 410 \frac{\text{CUBIC FEET}}{\text{MINUTE}}$$

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APPENDIX E

GIVEN NO SIGNIFICANT BUILDING INTERNAL RESISTANCE, AND ASSUMING INDOOR AND OUTDOOR TEMPERATURES ARE CLOSE TO 80°F, THE FLOW DUE TO STACK EFFECT IS:

$$Q = 9.4 A \sqrt{h (t_i - t_o)} \quad \text{WHERE:}$$

Q = AIR FLOW, CUBIC FEET PER MINUTE;

A = FREE AREA OF INLETS, OUTLETS, SQ. FT.;

h = HEIGHT FROM INLETS TO OUTLETS, FT.;

t_i = AVERAGE TEMPERATURE OF INDOOR AIR IN HEIGHT h , °F.

t_o = TEMPERATURE OF OUTDOOR AIR, °F

9.4 = CONSTANT OF PROPORTIONALITY, INCLUDING A VALUE OF 65% FOR EFFECTIVENESS OF OPENINGS. THIS SHOULD BE REDUCED TO 50% (CONSTANT = 7.2) IF CONDITIONS ARE NOT FAVORABLE.

BASED ON EQUAL INLETS AND OUTLETS.

$$Q = 410 \text{ CUBIC FEET/MINUTE}$$

$$h = \sim 40 \text{ FEET}$$

$$t_i - t_o = 5^\circ\text{F}$$

$$410 = 9.4 A \sqrt{40(5)}$$

$$\frac{3 \text{ SQUARE FEET}}{\text{FEET}} = A$$

THE ACTUAL AREA OF INLET AND OUTLET IS 6 SQUARE FEET. HOURLY INTERNAL HEAT GAINS ARE REMOVED WITH A TEMPERATURE DIFFERENCE ($t_i - t_o$):

$$410 = 9.4 (6) \sqrt{40(t_i - t_o)}$$

$$t_i - t_o = \underline{1.3^\circ\text{F}}$$

$$A_{\text{INLET}} = A_{\text{OUTLET}} = \underline{6 \text{ SQUARE FEET}}$$

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APPENDIX G COST ANALYSIS of AUXILIARY HEATING

COST ANALYSIS FOR AUXILIARY HEATING SYSTEM

APPENDIX G

CENTRALIZED

AUXILIARY SYSTEM FOR ENTIRE BUILDING:

BOILER: 40 MBTUH x 80 APARTMENTS 3,200 MBTUH
\$14,700.00
(MEANS, MECHANICAL
AND ELECTRICAL
COST DATA)

PIPING: \$6.20 x (240 FT. x 4) + (100 FT. x 20)
TYPE L 50/50 1" ϕ \$18,352.00
(MEANS, COST DATA)

CHIMNEYS: 24" DIAMETER
\$77.00 x 240 \$18,480
HEIGHT ABOVE
ROOF PENETRATION.
(MEANS, COST DATA)

(REQUIREMENTS FOR HOT WATER TANKS AND RADIATORS DO NOT VARY FROM CENTRALIZED TO DECENTRALIZED SYSTEM.)

DECENTRALIZED

AUXILIARY SYSTEM FOR EACH UNIT:

UNIT HEATERS: 43,800 BTUH
\$230.00 TO \$300.00
\$300.00 x 80 \$24,000
(MEANS, COST DATA)

PIPING: \$6.20 x 24' / UNIT x 80
TYPE L 50/50 1" ϕ \$11,904.00
(MEANS, COST DATA)

CHIMNEYS: NONE REQUIRED; EACH HEATER IS
VENTED DIRECTLY TO THE EXTERIOR.

	BOILERS	PIPING	CHIMNEYS	TOTAL
CENTRALIZED	\$15,000.	\$18,000	\$19,000	\$52,000
DECENTRALIZED	\$24,000.	\$12,000	—	\$36,000

~30% SAVINGS WITH
DECENTRALIZED
SYSTEM.

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